Environment Canada Environnement Canada

UNDERSTANDING THE ENVIRONMENTAL ASPECTS OF ELECTRONIC PRODUCTS:

A LIFE CYCLE ASSESSMENT CASE STUDY OF A BUSINESS TELEPHONE

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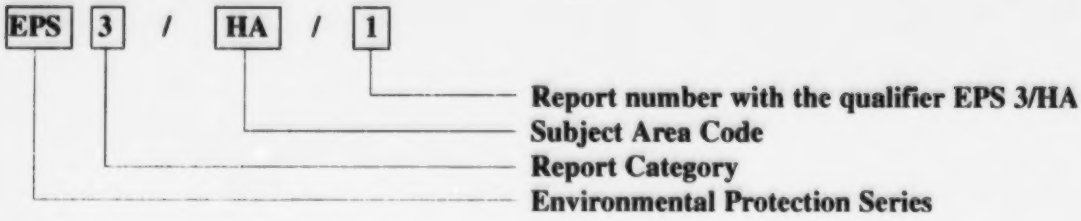

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Foreword

Environment Canada is publishing this case study to enhance the knowledge base in Canada and elsewhere with respect to new environmental management concepts and tools. While the telephone was the product system selected for this project, the concepts and tools described in this report can in essence be applied to any product system.

This case study summarizes a two-year joint project between Nortel Networks and Environment Canada to analyze the material, energy and environmental aspects of a common consumer product — the telephone. The particular telephone chosen was the Norstar M3710 which at the time was produced by Nortel Networks. The goal of the project was to better understand the potential economic and environmental benefits of emerging environmental management concepts such as product life cycle assessment and design for environment. Companies and, increasingly, national governments are using and promoting these tools to enhance the environmental performance of products. Since these tools also identify opportunities for improvements in energy and resource efficiency, they also provide companies with opportunities to reduce costs and stimulate innovation.

Environment Canada is a department of the Canadian federal government. It administers a variety of acts and regulations designed to protect and preserve the environment. Its goal is to make sustainable development a reality through the application of science and collaboration with citizens, business, industry, Aboriginal people and non-governmental organizations.

Nortel Networks is a global leader in telephony, data, eBusiness and wireless solutions for the Internet. It serves carrier, service provider and enterprise customers in more than 150 countries.

Acknowledgements

Many organizations and individuals contributed to this project, which was funded by the Environmental Protection Service of Environment Canada and Nortel Networks. Ecobalance Inc., with Remi Coulon acting as overall project manager, performed the life cycle assessment study. Ecobalance was supported by Larry Whittle, formerly of Water Technology International, and Steven Young, currently with Five Winds International. Tim Leah of the National Office of Pollution Prevention acted as the project manager for Environment Canada. Kevin Brady of Five Winds International prepared this case study and was involved in initiating the project at Environment Canada. Curtis Harnanan of Five Winds International provided editorial support. Numerous employees of Nortel Networks were also involved in the project.

Table of Contents

FOREWORD iv

ACKNOWLEDGEMENTS iv

LIST OF TABLES vii

LIST OF FIGURES vii

EXECUTIVE SUMMARY ix

1.0 INTRODUCTION: PRODUCT-FOCUSED ENVIRONMENTAL MANAGEMENT 1

2.0 TOOLS FOR PRODUCT-FOCUSED ENVIRONMENTAL MANAGEMENT — LIFE CYCLE ASSESSMENT AND DESIGN FOR ENVIRONMENT 3

2.1 Life Cycle Assessment 3

2.2 Design for Environment 4

3.0 PROJECT OVERVIEW 7

3.1 Project Objectives and Benefits 7

3.2 Project Organization 7

4.0 STUDY SCOPE AND METHODOLOGY 9

4.1 Project System Boundaries 9

4.2 Data Collection 10

4.2.1 Manufacturing 10

4.2.2 Distribution Phase 10

4.2.3 Use Phase 10

4.2.4 End-of-Life Phase 10

4.3 Inventory Flows and Impact Assessment 10

4.4 Modelling 10

4.4.1 Upstream System Boundaries — Parts and Components 10

4.4.2 Assembly — Nortel Networks Calgary 11

4.4.3 Distribution and Use 11

4.4.4 End-of-Life Options 12

4.4.5 KSU Analysis and DfE Scenarios 12

5.0 RESULTS 15

5.1 Greenhouse Gas Baseline Indicator Results 15

5.2 Analysis of Scenarios 18

5.2.1 Comparison of impact of KSU versus M7310 Telephone 18

5.2.2 New Keypad Technology 18

5.2.3 Thin-Walled Housing 20

5.2.4 End-of-Life Options 20

6.0 PEER REVIEW PROCESS 23

7.0 CONCLUSIONS 25
7.1 Implications of Life Cycle Analysis Results 25
7.2 Potential Improvement Scenarios 25
7.3 Using LCA as a DfE Tool 26
7.4 Summary Conclusions 26

GLOSSARY OF TERMS 27

REFERENCE MATERIALS AND KEY CONTACT INFORMATION 29

APPENDIX: OTHER BASELINE LIFE CYCLE IMPACT INDICATOR RESULTS 31
I. Raw Material Depletion 31
II. Ozone Depletion Potential 35
III. Air Acidification 36
IV. Eutrophication 39

List of Tables

Table 1 Innovation, Competitiveness and Design for Environment 5
Table 2 Nortel Networks M7310 Power Consumption 12
Table 3 Typical Material Content and Fate of Shredded Telephone 12

List of Figures

Figure 1 Stages in a Generic Product Life Cycle 3
Figure 2 Generic Product System Life Cycle and Its Interaction with the Environment 4
Figure 3 General LCA System Boundaries for the M7310 Business Telephone 9
Figure 4 Assembly and Surface Mounting Process at Nortel Networks Calgary 11
Figure 5 Greenhouse Gas Effect — Baseline Life Cycle Phases. 16
Figure 6 Greenhouse Gas Effect — Baseline Manufacturing Phase 16
Figure 7 Greenhouse Gas Effect — Baseline Set Comm 17
Figure 8 Greenhouse Gas Effect — Baseline C84 Chip 17
Figure 9 Greenhouse Gas Effect — Baseline Set Comm Printed Wire Board 18
Figure 10 Comparison of Baseline M7310 Telephone and KSU Impacts 19
Figure 11 New Keypad Scenario — Total Life Cycle 19
Figure 12 Reduced Housing Scenario — Total Life Cycle 20
Figure 13 Greenhouse Gas Effect — End-of-Life Phase 21
Figure 14 Raw Material Depletion — End-of-Life Phase 21
Figure 15 Air Acidification — End-of-Life Phase 22
Figure 16 Eutrophication — End-of-Life Phase 22
Figure I.1 Material Depletion for the Life Cycle Phases of an M7310 Telephone 31
Figure I.2 Raw Material Depletion for the Various Components during Manufacture of an M7310 Telephone 32
Figure I.3 Raw Material Depletion for the Cords of an M7310 Telephone 32
Figure I.4 Raw Material Depletion for Processes at Nortel Networks Calgary during M7310 Assembly 33
Figure I.5 Raw Material Depletion for the Set Comm of an M7310 Telephone 33
Figure I.6 Raw Material Depletion for the PCP Set (not including C84, A83 or printed wire board) of an M7310 Telephone 34
Figure I.7 Raw Material Depletion for Individual Capacitors 34
Figure I.8 Raw Material Depletion for the Set Comm Printed Wire Board of an M7310 Telephone 35
Figure II.1 Ozone Depletion Potential for the Life Cycle Phases of an M7310 Telephone 35
Figure III.1 Air Acidification for the Life Cycle Phases of an M7310 Telephone 36
Figure III.2 Air Acidification in the Manufacturing Phase of an M7310 Telephone 37
Figure III.3 Air Acidification for the Set Comm of an M7310 Telephone 37
Figure III.4 Air Acidification for the Set Comm Printed Wire Board of an M7310 Telephone 38
Figure III.5 Air Acidification for the C84 Chip of an M7310 Telephone 38
Figure IV.1 Eutrophication Effects for the Life Cycle Phases of an M7310 Telephone 39
Figure IV.2 Eutrophication Effects for the Manufacturing Phase of an M7310 Telephone 40
Figure IV.3 Eutrophication Effects for the Set Comm of an M7310 Telephone 40
Figure IV.4 Eutrophication Effects for the Set Comm Printed Wire Board of an M7310 Telephone 41

Executive Summary

The last few years have seen rapid growth worldwide in a field that can broadly be described as product-oriented environmental management. National governments and international organizations, as well as leading industrial companies, have been developing product-focused policies, regulations and tools to support traditional facilities and toxic substance-based approaches to environmental protection.

For government, these new approaches include product stewardship initiatives, extended producer responsibility programs, product standards, and expanded environmental criteria for procurement and environmental labelling programs. In the private sector, key tools and concepts being used by companies include environmental management systems, eco-efficiency, environmental education programs, life cycle costing, design for environment, design for disassembly, and product life cycle management. Progressive governments and companies now recognize that by focusing on reducing the inputs (materials and energy) and outputs (environmental releases) associated with a product's life cycle, they can improve the environmental performance of products while increasing their economic and market performance.

This case study describes a pilot project undertaken by Environment Canada and Nortel Networks to demonstrate the usefulness of two of these tools, life cycle assessment (LCA) and design for environment (DfE), for designing products that are more environmentally friendly. LCA is the preferred tool available today to scientifically assess the environmental performance of products. The goal of an LCA study is to measure, evaluate and report the resource requirements (raw materials and energy) and environmental emissions (to air, water and land) associated with the product system being evaluated. The unique feature of LCA is that the data are collected across the product life cycle (raw materials, manufacturing, use and disposal) and across different environmental media (air, water and land). Thousands of LCA studies have been performed by industry and government over the last decade on products such as consumer packaging, beverage containers, appliances, automobiles and paper products such as newsprint and magazines.

DfE is the integration of environmental considerations into product and process design. Although not as widely practised as LCA, DfE is potentially one of the most significant tools available for reducing the environmental impacts of products. This significance stems from the fact that once a product or process moves from the drawing board into production, its environmental attributes are largely fixed, subject primarily to methods of use and disposal. By understanding clearly the implications of materials, production processes, use patterns and disposal options, designers can substantially improve the environmental and the economic performance of the products they help to create. Fundamental to DfE is the use of tools such as LCA, which provide accurate information on the environmental aspects of product systems.

The aim of this project was to conduct an LCA on a manufactured product, the M7310 business telephone, and to identify potential design improvement strategies for electronic products. The project was initiated to:

- demonstrate the business value of using LCA and DfE to improve the environmental and economic performance of products;
- develop guidelines for environmental design improvements for the next generation of electronic products; and
- give Environment Canada experience and understanding of product-focused approaches (as opposed to facility-based approaches) to achieving environmental objectives.

The telephone was studied because it is a well-known and sophisticated product, employing many of the technologies and manufacturing processes used for larger and more complex electronic products. The project was initiated in January 1997 and was completed in the fall of 1998. The LCA portion of the project was subject to an independent review to ensure consistency with international standards for life cycle assessment and to evaluate whether the study met its stated goals.

The LCA study examined the material and energy flows and environmental releases associated with the M7310 business telephone. The functional unit for this study (the reference value to which the energy, material and environmental release data were normalized) was defined as the service provided by

the product, over its life span, including refurbishing. The M7310 includes typical features such as display functions (including time, date and calling information), programmable memory buttons, hold button, intercom system and a handsfree feature. It should be noted that the telephone set itself is not self-sufficient and must be accompanied by a key system unit (KSU) central system to which 12 telephones are attached. The KSU was not included as part of the functional unit for the LCA. However, its effects were assessed to provide some perspective on the impacts of the telephone alone versus those of the telephone plus the KSU.

In addition to the baseline study of the telephone set, this project included an investigation of a number of potential design improvement (DfE) scenarios. These scenarios included an evaluation of:

- new keypad technology;
- thin-walled plastic housing; and
- alternative end-of-life options.

The results of the LCA study and its implications for potential design improvement strategies are summarized in the following paragraphs.

Reducing electricity consumption during the use phase and during electronics manufacturing (especially for integrated circuits) would lead to reductions in greenhouse gas emissions and air acidification. Reductions in electricity consumption could be achieved through a variety of design strategies such as power-down features and the use of lower-power integrated circuit (IC) technology. The business case is generally favourable for this kind of improvement, since it reduces the cost of product ownership for customers, particularly those using larger and more complex electronic products such as central office switches.

IC manufacturing ranked first in terms of environmental impacts at the manufacturing stage. The fact that IC processing is complex and energy-intensive is not unexpected. What is surprising is that it often dwarfs the impact of other components on which LCA/DfE has traditionally placed an emphasis (such as plastic or metal housing, packaging and surface treatments). This finding may encourage changes in how the electronics industry defines and designs its products.

When normalized per telephone, the impacts of the KSU proved to be three to five times larger than those of the telephone, indicating potential savings from a DfE approach to this part of the overall telephone system. This result is not surprising since most of the system intelligence and functionality is embodied in the KSU. Although it is difficult to generalize to other products and systems, this result may also help guide future decisions on where to focus LCA and DfE efforts for complex electronic systems.

The scenario analysis indicated that the proposed new keypad technology and thin-walled housing did not significantly affect the total life cycle impact of the telephone. However, the case for these scenarios can still be made in terms of reduced assembly and manufacturing costs and potential ease of disassembly.

The end-of-life scenario analysis looked at the effects of changing the ratio of phones that are sent to shredding at a facility in West Chicago, Illinois, rather than to a copper smelter in Rouyn-Noranda, Quebec. This analysis highlighted the trade-offs that are often inherent in evaluating end-of-life management options. The results showed that shredding is preferred to minimize raw material depletion and eutrophication. However, copper smelting is preferred to minimize greenhouse gas effect and air acidification.

General Lessons Learned from the Project

1. The study confirmed that life cycle analysis is a systematic and useful tool for identifying the largest environmental impacts from a product throughout its life cycle. It is particularly useful for putting the many different environmental impacts from a product in perspective and identifying the dominant impacts. The results from an LCA can then be used to focus subsequent DfE efforts to ensure that limited resources are applied to the largest environmental burdens from the product.

2. Due to timing and resource constraints, a number of DfE scenarios were explored prior to the completion of the LCA study. These DfE scenarios had little effect on the total life cycle impact for all impact categories and inventory flows, and this finding confirmed the need for good LCA data to guide the DfE process.

3. To ensure relevance and management interest, LCA should be linked as much as possible to economic analysis. Further work would be required to more fully understand the cost-reduction opportunities that may arise from LCA.

4. The time and resource (people and dollar) requirements for completing the LCA, using the traditional methodology described, were high. This is not unexpected when an organization is completing an initial LCA exercise, and costs could be expected to decrease with experience. However, given that product development cycles in many industries are becoming shorter, it may not be realistic to include traditional LCA as part of a "live" product development process. Rather, LCA should be seen as an "off-line" DfE tool for identifying key strategies and guidelines for next generation product design.

5. The most challenging aspect of an LCA is the lack of access to good data. Although the data are often tracked, they are not collected centrally nor are they easily adapted for LCA purposes (e.g., environmental emissions from a site are not usually allocated to specific products). In addition, data collection from primary sources can be particularly time-consuming.

6. There is an ongoing need for simple and sophisticated DfE tools that can be easily integrated into existing design processes.

From a general perspective, the project provided insights into the complexity of product systems such as the telephone, and the utility of tools such as LCA and DfE in improving the environmental performance of product systems.

1.0 Introduction: Product-Focused Environmental Management

Traditionally, regulators and industry have focused their environmental activity on facilities and toxic substances. In the last few years, however, there has been rapid growth internationally, particularly in Europe and Asia, in a field that can be broadly described as product-oriented environmental management. National governments and international organizations have been developing product-focused policies and regulations, voluntary product stewardship initiatives, mandatory extended producer responsibility and product take-back programs, as well as expanded environmental criteria for procurement and environmental labelling programs.

In the private sector there has been an even greater level of activity as companies have begun to translate environment from a compliance-driven cost centre to a core business issue that relates directly to efficiency and competitiveness. This trend has been catalyzed by a shift in emphasis from operations and facility-based environmental management to product- and supply-chain-focused activity. The result for many leading companies has been a greater integration of environmental considerations into business activities such as procurement and supply, product design and corporate strategy. Progressive companies now recognize that by focusing on reducing the inputs (materials and energy) and outputs (environmental releases) associated with a product's life cycle, they can improve the environmental performance of their products while increasing their economic and market performance.

Just as environmental management systems have been an important tool for identifying and improving the environmental management of organizations, a number of tools have been developed for examining environmental issues related to product systems. Key tools and concepts being used by companies include life cycle costing, design for environment (DfE), design for disassembly and product life cycle assessment (LCA).

This case study describes a pilot project undertaken by Environment Canada and Nortel Networks to demonstrate the usefulness of two of these tools, LCA and DfE, for designing products with better environmental performance. This project is unique in that it is the first Government of Canada–industry partnership that has examined the entire life cycle of a manufactured product.

The remainder of this case study introduces the concepts of LCA and DfE (Section 2), describes the genesis of the project and the objectives of the participating organizations (Section 3), details the study scope and methodology (Section 4), presents the results (Section 5), describes the peer review process (Section 6) and discusses the overall conclusions of the study (Section 7).

2.0 Tools for Product-Focused Environmental Management — Life Cycle Assessment and Design for Environment

2.1 Life Cycle Assessment

The preferred tool available today to scientifically assess the environmental performance of products is life cycle assessment (LCA). The goal of an LCA study is to measure, evaluate and report the resource requirements (raw materials and energy) and environmental emissions (to air, water and land) crossing the boundaries of a defined service system. In the case of a product LCA, the product system encompasses all processes from the extraction of raw materials, through manufacturing, to use and end-of-life activities, see Figure 1. The interactions between a generic product system and the environment are shown in Figure 2.

When applied in an industrial context, LCA is about systems analysis and more informed decision making. The tool has three general dimensions:

1. **Flowchart and inventory of the life cycle stages.** The physical sequence of activities in a product system are mapped out and input and output data are collected.
2. **Analysis of multiple environmental and resource issues.** An LCA study tracks inputs of resources from the environment (energy and materials) and outputs to the environment (releases to air, water and land). This dimension is LCA's greatest strength. Because it is not a single-issue tool, it exposes trade-offs across the product life cycle.
3. **Assessment of potential impacts.** LCA extends beyond quantitative measurement and analysis to a point where an assessment of the potential environmental impacts of the product system occurs. This assessment is interpreted in light of the goals of the study and the values of the proponents. To assist in this assessment, specific indicators related to impact categories are developed. For example, a study might report on a product's contribution to climate change using the indicator of carbon dioxide (CO_2) equivalents per unit of production.

Figure 1 Stages in a Generic Product Life Cycle

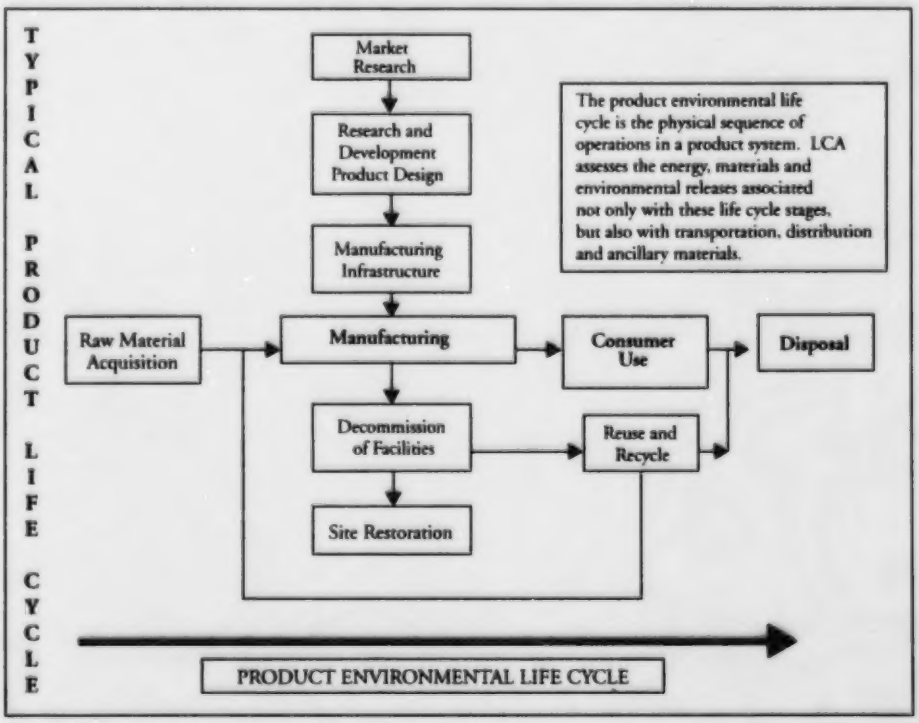
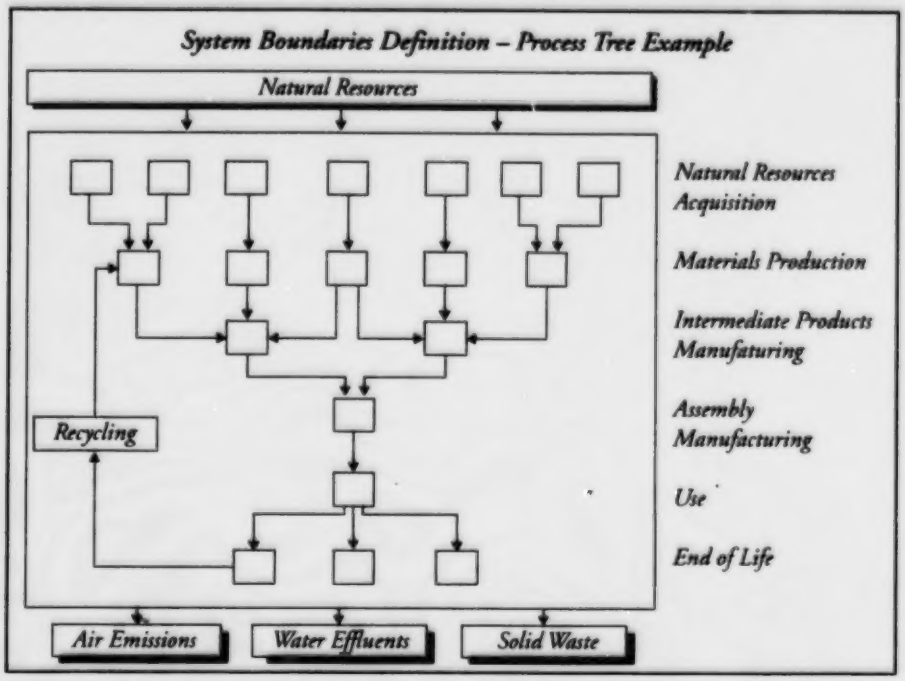

TYPICAL PRODUCT LIFE CYCLE
Market Research
Research and Development Product Design
Manufacturing Infrastructure
Raw Material Acquisition
Manufacturing
Consumer Use
Disposal
Decommission of Facilities
Reuse and Recycle
Site Restoration
The product environmental life cycle is the physical sequence of operations in a product system. LCA assesses the energy, materials and environmental releases associated not only with these life cycle stages, but also with transportation, distribution and ancillary materials.
PRODUCT ENVIRONMENTAL LIFE CYCLE

Figure 2 Generic Product System Life Cycle and Its Interaction with the Environment



Life cycle studies have various applications. Specifically, they can assist in:

- identifying opportunities to improve the environmental aspects of products at various points in their life cycle;
- decision making in industry, governmental or non-governmental organizations (e.g., strategic planning, priority setting, product or process design or redesign);
- the selection of relevant indicators of environmental performance, including measurement techniques; and
- the marketing of a product (e.g., an environmental claim, ecolabelling scheme or environmental product declaration).

2.2 Design for Environment

Once a product or process moves from the drawing board into production, its environmental attributes are largely fixed, subject primarily to methods of use and disposal. This realization has led to a growing interest in design for environment (DfE), also known as ecodesign or green product design. The concept of DfE is straightforward: comprehensive and basic environmental improvements can be effected at the point of product design. These are achieved by adding

LCA and Sustainable Development

Although definitions of sustainable development have frequently proved elusive, it is clear that any move toward industrial sustainability (lower relative consumption of energy and raw materials, reduction or elimination of waste) will affect all stages of a product's or process's life cycle. It will require new design principles based on a global and holistic approach to reducing environmental impacts: global because these impacts transcend national borders, holistic because short-term, piecemeal solutions to address a succession of issues in isolation will be less and less effective. One important means of integrating environmental issues into industrial design and operations is the adoption of life cycle assessment, which is the best, holistic, approach to measuring cleanliness. The LCA approach must always consider the "boundaries," that is the points in a multi-step process at which an LCA is to begin and to end.

Source: OECD Directorate for Science, Technology and Industry, Committee for Scientific and Technological Policy, report on Biotechnology for clean industrial products and processes.

environmental criteria to the design list at the same time as technical and economic constraints are defined. In principle, far-reaching improvements can be made across the product system, from materials to manufacture, to product use and end of life. Table 1 provides examples of how DfE considerations can contribute to environmental improvement, innovation and competitiveness.

Design for Environment (DfE) is the integration of environmental considerations into product and process design. Fundamental to DfE is the use of tools and practices such as LCA that encourage environmental responsibility and simultaneously reduce costs, promote competitiveness and enhance innovation.

Putting DfE into practice involves improving an organization's capacity to integrate environmental criteria at the conceptualization and design stages. To achieve this designers need to:

- be sensitized to the environmental aspects of the materials and processes selected;
- have access to simplified data and indicators that enable them to make informed choices when selecting materials; and
- understand the life cycle impacts of the products they are working with.

In many cases, LCA studies help address these needs by providing designers and product development teams with a greater understanding of the environmental aspects of the products they design.

Table 1 Innovation, Competitiveness and Design for Environment

Product Service	Example Design Change	Innovation	Competitive Advantage
Single-serving paper package for sugar	Package is reshaped from a 46-cm sachet to a 10-cm cylinder	• Paper quantity is reduced by 30% • Allows for smaller secondary package and increased packing efficiency	• Improved marketability, due to new "feel," ease of use and heightened aesthetic appeal
Electronic equipment	Stand-by power consumption is reduced by orders of magnitude	• Power is stored and available "on demand" to reactivate the device	• Reduced cost of operation • Reduced radiative energy
Polymer moulding	Recycled plastic is sandwiched between virgin polymer on inner and outer surfaces	• Provides up to 40% recycled content in product • Aesthetic and technical properties of both surfaces are preserved	• Reduced costs of raw materials • Marketing of environmentally improved product
Combining an automobile alternator with the starter motor	One component serves two functions	• Vehicle weight is reduced, fuel economy is improved, fewer parts are needed	• Lower cost of production • Reduced weight improves vehicle performance
Carpet tiles	Removal of potentially hazardous and volatile compounds	• New processes that eliminate toxic substances reduce costs and improve quality	• Reduced or eliminated off-gassing — carpet does not contribute to reduced indoor air quality • Lower cost of production • Reduced end-of-life risk — no toxic substances to leach into landfill — leading to reduced business risk

3.0 Project Overview

3.1 Project Objectives and Benefits

The aim of this joint project between Environment Canada and Nortel Networks was to conduct a life cycle assessment (LCA) on a manufactured product, the M7310 business telephone, in order to identify improvement strategies. Specifically, the project was initiated to:

- demonstrate the business value of using LCA and design for environment (DfE) to improve the environmental and economic performance of products;
- develop guidelines for environmental design improvements for products; and
- give Environment Canada experience with, as well as an understanding of, product-focused approaches (as opposed to facility-based approaches) to achieving environmental objectives.

The telephone was chosen for study because it is a well-known and sophisticated product, employing many of the technologies and manufacturing processes used for larger and more complex electronic products.

From Environment Canada's perspective, the project offered several benefits. For example, it gave the Department an opportunity to co-operate with industry in a type of study that, because of its links to economic competitiveness, is most often carried out behind closed doors. As well, it enabled the Department to gain important experience in working with industry to achieve societal objectives such as pollution prevention and greenhouse gas reduction. Finally, the telephone study was a desirable demonstration project because the telephone is a common product that is used daily by most Canadians. This commonality would help in communicating the study results.

3.2 Project Organization

The LCA study was initiated by Environment Canada's National Office of Pollution Prevention and Nortel Networks. Environment Canada and Nortel Networks developed the project scope and managed the project. In addition, Nortel Networks provided access to data and key personnel within the company.

The LCA study was undertaken by the consulting company Ecobalance Inc. Data collection support was provided by Water Technology International and Five Winds International.

The results of the study underwent a peer review process (see Section 6), chaired by Scott Chubbs of the consulting company Virterra Inc. Mr. Chubbs is an internationally recognized life cycle expert and a member of the Canadian Standards Association advisory committee on LCA.

The project was initiated in January 1997 and completed in the fall of 1998.

4.0 Study Scope and Methodology

The functional unit for this LCA study was defined as the service provided by the product, the M7310 business telephone, over its life span, including refurbishing. The M7310 includes features such as:

- display functions including time, date and calling information;
- programmable memory buttons;
- hold button;
- intercom system; and
- handsfree feature.

This telephone set is not self-sufficient and must be accompanied by a key system unit (KSU) central system to which 12 telephones are attached. The KSU was not included as a part of the functional unit for the baseline LCA. However, the effects of the KSU, on a per telephone basis, were compared with those of the telephone itself to give some perspective.

In addition to the baseline (LCA) study of the telephone set, this project included an investigation of a number of potential design improvement (DfE) scenarios. These scenarios included:

- new keypad technology;
- thin-walled plastic housing; and
- alternative end-of-life options.

These scenarios are described in further detail in Section 4.4.5.

4.1 Project System Boundaries

Figure 3 shows the system boundaries for the life cycle analysis of the M7310 business telephone. The modelling of the different phases is detailed below in Section 4.4.

Figure 3 General LCA System Boundaries for the M7310 Business Telephone

Raw Materials and Fuel Use
Electronics Components and Materials
Nortel Assembly (Calgary)
Other Parts and Chemicals
Refurbished
Repair and Distribution Center (Nashville, Tennessee)
Use Phase (United States)
Recalmation Center (Durham, North Carolina)
Copper Smelting (North America)
Shredding (North America)
Air Emissions, Water Effluents and Solid Waste

4.2 Data Collection

The data used in the analysis were compiled in the following ways:

4.2.1 Manufacturing

Materials, processes and simple electronic components (e.g., resistors, capacitors) were modelled using data in Ecobalance's DEAM™, a comprehensive life cycle inventory database consisting of several thousand data sets for use within Ecobalance's TEAM™ Life Cycle Assessment Software.

As well, questionnaires were sent out to suppliers of major electronic components requesting life cycle inventory information on all the manufacturing aspects of each component. The components were:

- the C84 integrated circuit (IC) chip — the main telephone chip on the printed wire board of the terminal;
- the A83 IC chip — a telephone chip on the printed wire board of the terminal;
- the printed wire board — the main board;
- the chip on board for the liquid crystal display (LCD) assembly; and
- the Mylar film flexible circuits — the LCD assembly.

It should be noted that the data for A83 chip were modelled using data collected for the C84 chip. Also, the data for the chip on board were modelled using data from the C84 chip and the printed wire board.

4.2.2 Distribution Phase

Data on distribution were obtained by questionnaire and a site visit to Nortel Networks Nashville Logistics Center in Nashville, Tennessee.

4.2.3 Use Phase

Energy data were obtained from Nortel Networks Calgary in Alberta.

4.2.4 End-of-Life Phase

Data on this phase were obtained from Nortel Networks Nashville Repair and Distribution Center in Nashville, Tennessee, and Nortel Networks Reclamation Center in Durham, North Carolina. Data were acquired for shredding of the telephone and for copper smelting in the end-of-life phase.

4.3 Inventory Flows and Impact Assessment

Various impact indicators are available to convert inventory flows into environmental impacts. Because of their relevance to specific goals contained in the Nortel Networks corporate environmental policy, the following five impact indicators were used in this study (refer to the Glossary of Terms for definitions):

- global warming potential (greenhouse gas effect);
- raw material depletion index;
- ozone depletion potential;
- air acidification potential; and
- eutrophication potential.

Inventory flows are typically reported in inventory categories such as energy, carbon monoxide, particulate matter, total volatile organic compounds, and total metals in air and water. This study used the following specific inventory flow categories:

- total primary energy;
- particulate matter (air);
- carbon monoxide (air);
- total hydrocarbons (air);
- total metals (air);
- total suspended solids (water);
- total metals (water);
- total hazardous waste; and
- total non-hazardous waste.

4.4 Modelling

This section describes in more detail the modelling of each of the different phases of the M7310 business telephone life cycle (i.e., upstream system boundaries, assembly, distribution and use, and end of life) and describes the various DfE scenarios.

4.4.1 Upstream System Boundaries — Parts and Components

This section outlines the organization of the parts list of the telephone as well as the modelling of supplier components.

Some 150 parts, subcomponents and components constitute the parts list for the M7310 business telephone. The parts list was grouped into similar items to produce a manageable list from which to model the telephone. This was done by combining parts, subcomponents and components into general categories that consisted of parts or components made up of similar materials and manufactured by similar processes. For example, all 44 ceramic capacitors were analyzed as identical components regardless of their individual capacitance.

The modelling of the M7310 business telephone correlated selected parts, components, and subcomponents with corresponding materials and processes. Three main sources of data were used to model these categories:

- *For complex components (ICs, chip on board, printed wire board, Mylar conductive film)*, supplier data — external and internal — were used.
- *For simpler electronic components (resistors, capacitors, diodes, etc.)*, ready-made component modules that included environmental impact data for a complete module (e.g., a resistor module) from Ecobalance's comprehensive database on electronic parts were integrated into the model.
- *For non-electronic parts*, material and process modules from Ecobalance's DEAM™ database that together model a component or part (e.g., model a telephone cover as ABS plastic) were used.

4.4.2 Assembly — Nortel Networks Calgary

Figure 4 illustrates the assembly process which at the time was undertaken at the Nortel Networks Calgary facilities.

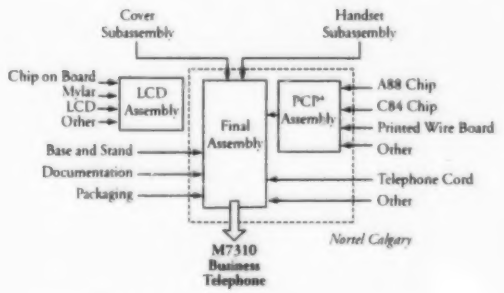
In addition to the assembly processes shown in Figure 4, resistors, capacitors, chips and other components are surface-mounted onto the printed wire board. These electronic components are shipped in from external and internal suppliers. The modelling of this stage of the life cycle was accomplished by:

- collecting electricity consumption data for the assembly and surface-mounting processes per telephone;
- collecting data on consumables and waste emissions for the assembly, surface-mounting processes and packaging of the components; and
- applying a formula of:

  weight of component × *distance transported*

  to model the transportation of the electronic components to the assembly facility. Only the top 10 components (constituting approximately 80 percent of the weight of the telephone) were included for the effects of transportation to the assembly facility.

Figure 4 Assembly and Surface Mounting Process at Nortel Networks Calgary



4.4.3 Distribution and Use

In 1997 the M7310 telephone was manufactured in Calgary, Alberta, and shipped to the Nortel Networks Nashville Logistics Center (NLC) for distribution within the United States. NLC processed orders primarily from other distribution centres throughout the United States, but in some cases would supply products directly to the consumer (i.e., end user). Small orders were repackaged by NLC prior to distribution, whereas larger orders were shipped directly to the distribution centres once received from Calgary. NLC also distributed other Nortel Networks products, but data collection for this study was limited to the M7310 telephone.

The distribution stage was modelled as follows:

- There is a 3,380 km (2,100 mile) journey from Calgary to NLC in Nashville. The material shipped includes a telephone weighing 1.41 kg (3.1 lbs.), as well as packaging material (wood pallet, polyethylene packaging and wrap) weighing 0.25 kg (0.55 lb.)/telephone. Transportation is approximately 90 percent by road and 10 percent by air.
- The packaging was assumed to be sent to a landfill. This excludes pallets: 80 percent of these go to landfill while the rest are reused.
- An average road journey of 1,020 km (635 miles) then takes place from NLC to another distribution centre or directly to the customer. For this study, it was assumed that 80 percent of the telephones were shipped as is, with the other 20 percent being repackaged into smaller packages for individual customers. These

smaller packages consist of a carton of nine telephones, each wrapped individually in its own box. The carton plus box weigh 0.11 kg (0.24 lb.)/telephone.

During the use phase, each telephone consumes 292.3 kJ/week (15 MJ per annum) of electricity (direct electric power) (see Table 2).

4.4.4 *End-of-Life Options*

The system boundaries were extended to include the shredding and copper smelting processes associated with the end-of-life phase of the M7310. For the baseline case, it was assumed that 50 percent of the telephone was shredded for material separation, while the other 50 percent was sent for copper smelting. Table 3 provides the typical materials and their fate in a shredding operation.

4.4.5 *KSU Analysis and DfE Scenarios*

To gain some perspective on the relative impacts of the M7310 telephone set and KSU, the following aspects of the KSU were analyzed:

- Energy consumption during the use phase, since energy is typically an environmental factor in electronics products — 1,034 MJ per annum;
- Scaled impacts of the following KSU components attributable to the telephone set:
  - printed wire board;
  - plastics (principally ABS); and
  - chips and electronics.

The following DfE scenarios were modelled. Note that these scenarios represent potential design options and not necessarily planned ones.

Table 2 Nortel Networks M7310 Power Consumption

Modes	Current (mA)	Voltage (v)	Hours per Working Day	% of Working Day	% Weekend	% Whole Week	Energy Consumption (K J / Week)
Idle	24.1	19	19	79.2	100.0	85.1	235.7
Handset	27.7	19	3	12.5	0.0	8.9	28.4
Handsfree	41.1	19	2	8.3	0.0	6.0	28.1
TOTAL			24	100.0	100.0	100.0	292.3

Assumptions:

1. Standard model for proprietary telephones in a business environment.
2. Phone in use 5 hours per business day, 25 hours per week.
3. All power is provided over the line cord from the system KSU (Key Switching Unit).

Table 3 Typical Material Content and Fate of Shredded Telephone

Material	% of Weight	Fate
ABS	44.0	ABS recycling
Steel	8.9	Steel recycling
Non-ABS plastics	23.0	Solid waste (12%) and low-grade recycling (88%)
Circuit boards	2.6	Copper recycling
Copper	5.5	Copper recycling
Waste	0.4	Solid waste
TOTAL	84.4*	

* The remaining 15.6% is cardboard box, polymer wrapping and documentation.

New Keypad Technology

A more integrated keypad technology was investigated and modelled as:

- a dial key tree assembly — 60 g polybutylene terephthalate; and
- a bezel — 20 g polycarbonate/ABS blend (50/50).

Thin-Walled Housing

The issue of using less plastic for the telephone housing was investigated. The current telephone uses an ABS housing with a thickness of 2.3–3.0 mm (506 g). Under the new scenario, the housing would consist of a polycarbonate/ABS material (approximately 50/50) with a thickness of 0.8–1.0 mm (approximately 170 g).

End-of-Life Phase

In the baseline scenario for this study, 50 percent of the telephone was modelled as being shredded for materials separation, with 50 percent being sent for copper smelting/copper recovery. For an improvement scenario, different ratios of shredding and smelting were investigated.

5.0 Results

Two primary sets of results have been derived from this project. These are 1) the baseline life cycle impact indicator results and 2) the results of the key system unit (KSU) and design improvement scenario analyses.

For each impact indicator, the baseline life cycle impact indicator results point to:

- the life cycle phase that is the largest contributor to the indicator; and
- within specific life cycle phases (e.g., manufacturing), the activities that are the largest contributors to the indicator.

To illustrate the types of results generated by the life cycle analysis (LCA) study, Section 5.1 provides detailed information for the global warming (greenhouse gas) indicator. The baseline life cycle impact results for the other indicators (raw material depletion, ozone depletion, air acidification and eutrophication) are provided in the Appendix.

From a total life cycle perspective, the greatest contributors to the environmental impact of the M7310 telephone were 1) the use phase (electricity consumption) for the greenhouse gas and air acidification effects and 2) the component-manufacturing phase for raw material depletion and water eutrophication effects. Although representing a very small part of the final product in terms of weight, the main electronics subassembly, especially the application specific integrated circuits (ASICs) and the printed circuit board, were the largest contributors to greenhouse gas emissions during the manufacturing stage.

The second set of results relates to the KSU and scenario analysis. Here, the baseline indicator results were compared with those for the KSU and three modelled scenarios. This process identified which areas offer the greatest opportunity for improving the environmental performance of the product system. The results are provided in Section 5.2.

Two of the improvement scenarios, the proposed new keypad technology and thin-walled housing, did not significantly affect the total life cycle impact. However, the case for these scenarios can still be made in terms of reduced assembly and manufacturing costs (and potential ease of disassembly), and the results point to how LCA can be used in conjunction with other tools to implement an overall design for environment (DfE) approach.

5.1 Greenhouse Gas Baseline Indicator Results

Electricity consumption by the telephone in the use phase was the largest contributor to the greenhouse gas indicator (Figure 5). Although this model of telephone consumes only a small amount of electricity, this consumption occurs 24 hours a day, 7 days a week for over 10 years.

The second largest contributor to the greenhouse gas indicator was manufacturing. Within manufacturing most of the greenhouse gas contributions can be traced to the main electronics subassembly (Set Comm) (Figure 6). Further investigation showed that process electricity used for producing ASICs was the main source of these results.

Figure 5 Greenhouse Gas Effect — Baseline Life Cycle Phases

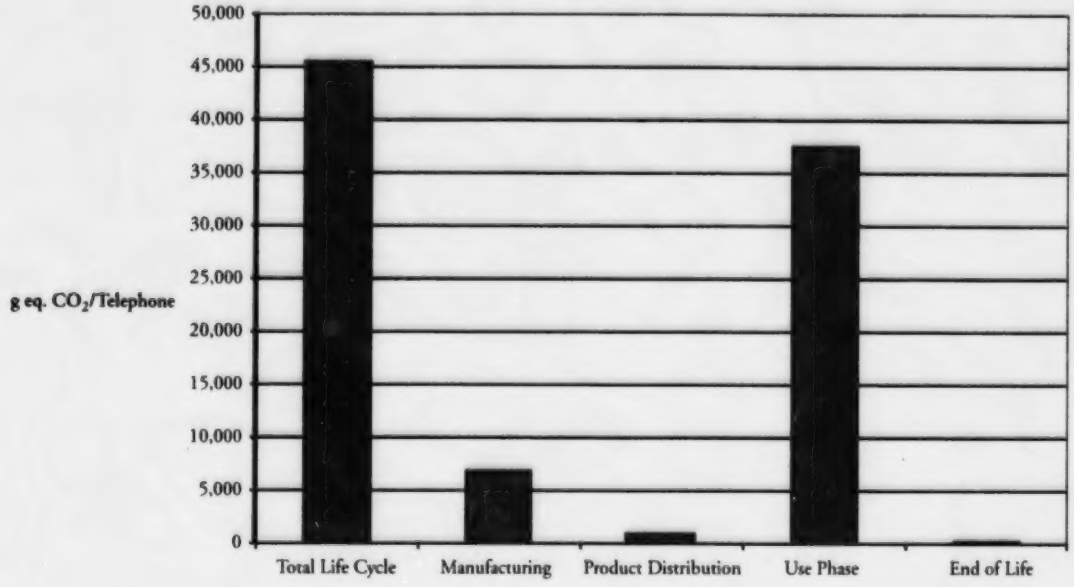
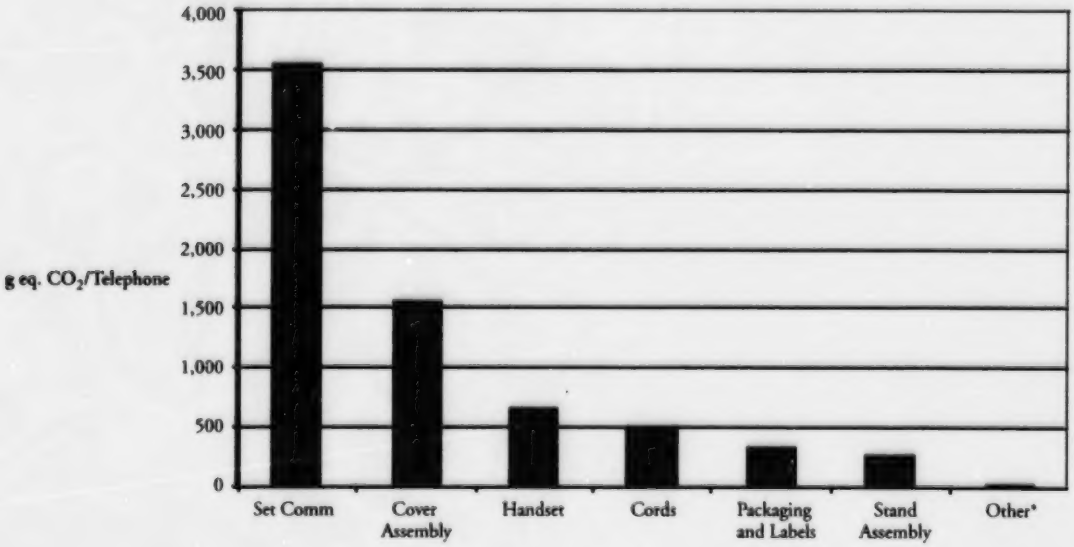
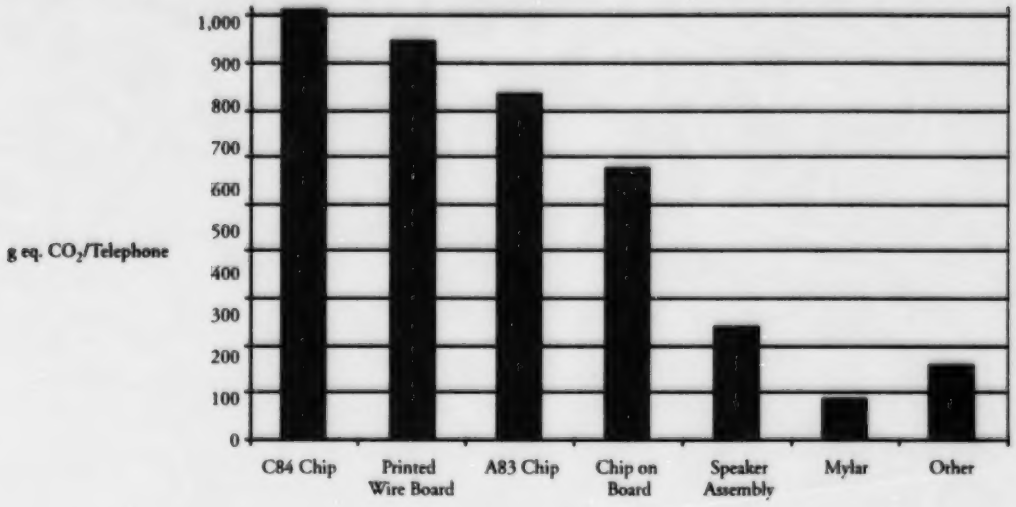


Figure 6 Greenhouse Gas Effect — Baseline Manufacturing Phase



* Consumables, assembly plant electricity

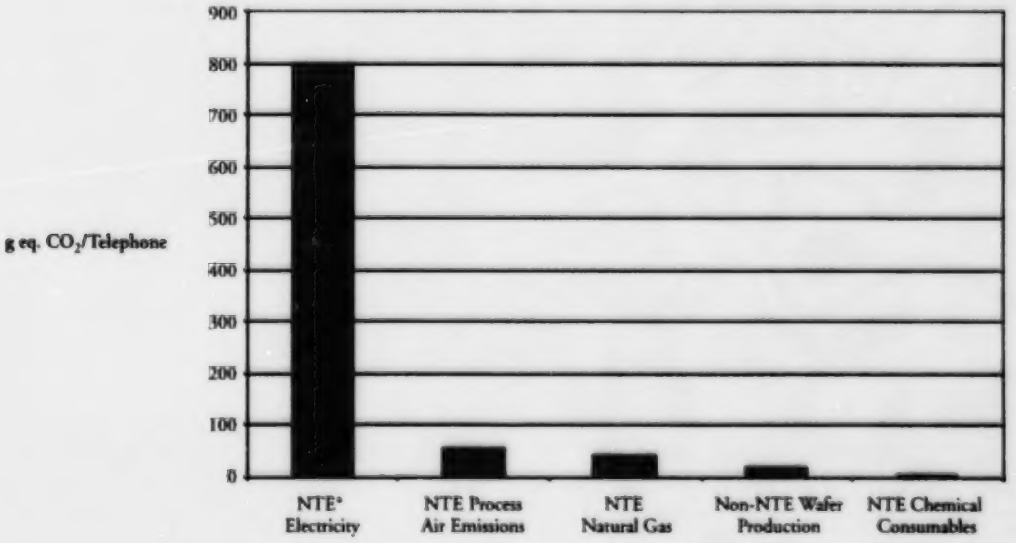
Figure 7 Greenhouse Gas Effect — Baseline Set Comm



Within the electronics subassembly (Set Comm), the C84 chip was the largest contributor to the greenhouse gas indicator (Figure 7).

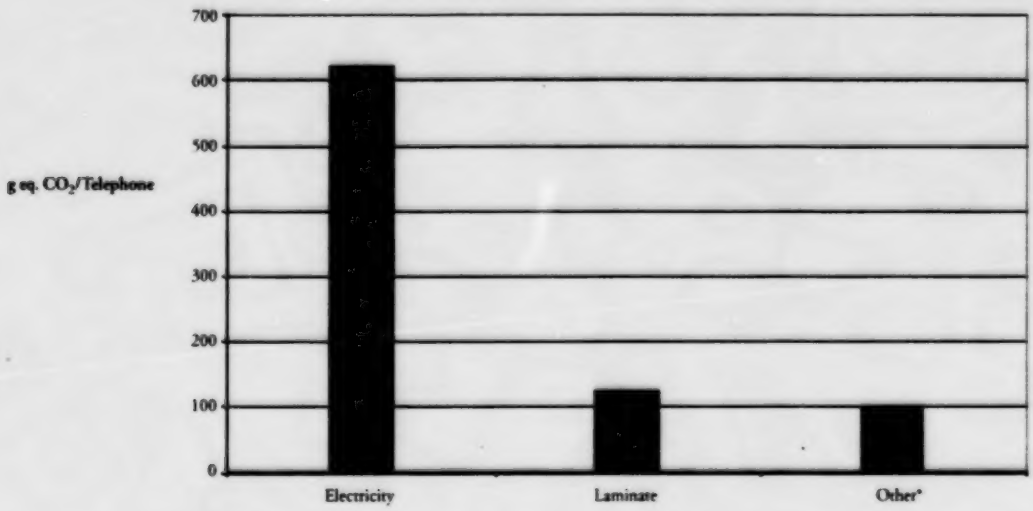
The potential greenhouse gas impact from the C84 chip stemmed principally from electricity use during chip processing at Nortel Networks Electronics (NTE) (Figure 8).

Figure 8 Greenhouse Gas Effect — Baseline C84 Chip



* Nortel Networks Electronics

Figure 9 Greenhouse Gas Effect — Baseline Set Comm Printed Wire Board



* Process emissions, component packaging and transport

Average U.S. process electricity usage was the main contributor to the greenhouse gas indicator for the printed wire board (Figure 9).

Figures 5 to 9 illustrate the level of understanding that can be gained from a life cycle study. Such studies show which parts of the product system make the greatest contributions to each impact indicator, in this case greenhouse gas effect. This allows designers to identify where the greatest opportunities for improvement lie and to make an informed comparison between the current design and alternative scenarios. This type of comparison is illustrated in the next section.

5.2 Analysis of Scenarios

The results of the KSU and scenario analyses described in Section 4.4.5 were compared with the baseline results. These findings are presented below.

5.2.1 Comparison of impact of KSU versus M7310 Telephone

Figure 10 shows the effects of the KSU (from a crude model) compared with those of the M7310 telephone. Only the manufacturing and use phases were compared so that the total impact shown is only from those two life cycle phases. Also, only 1/12 of the KSU impacts are shown since 12 phones work with one KSU.

Because of the large amount of energy consumed during the use phase, the KSU has much higher greenhouse gas and air acidification effects than the baseline telephone. Cords are the largest contributor to raw material depletion for the telephone, and since no cords were modelled for the KSU, the impacts in this category are lower for the KSU. The printed wire board is responsible for most of the eutrophication effects depicted for the KSU. In addition to the printed wire board, the packaging and labels are large contributors to the eutrophication associated with the telephone set itself. The packaging and labels were not modelled for the KSU. As well, this analysis does not include the building cables that connect each telephone to the KSU.

5.2.2 New Keypad Technology

Figure 11 shows the effects of the new keypad technology compared with the existing keypad technology of the baseline telephone. Since the keypad was not a major factor in any of the baseline impact indicators, changing it does not greatly affect the total life cycle impact of the telephone. Note that the impacts of the new keypad technology on the total life cycle indicators are within 0.4 percent of those of the baseline telephone.

Figure 10 Comparison of Baseline M7310 Telephone and KSU Impacts

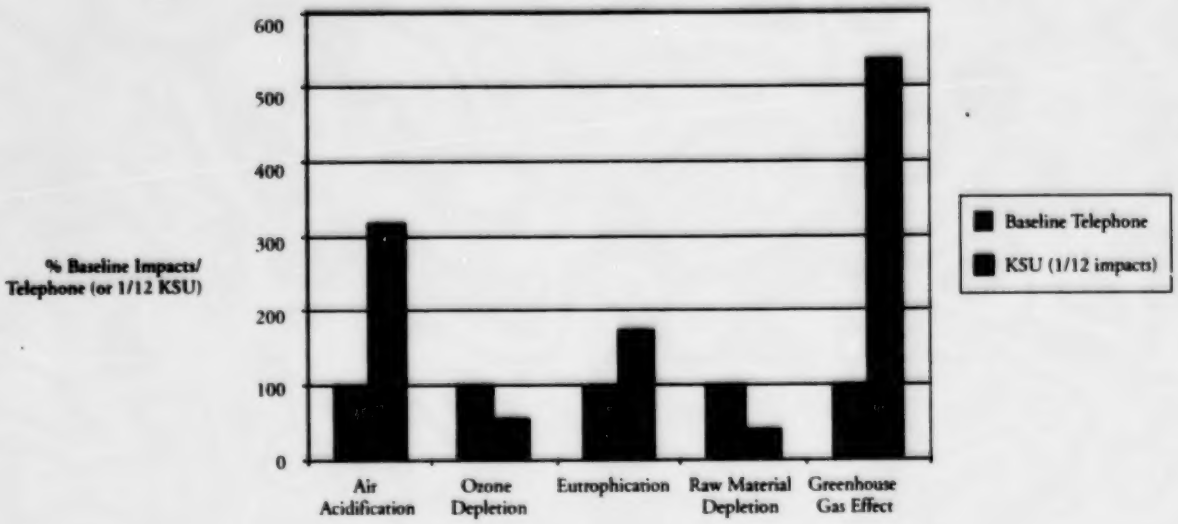
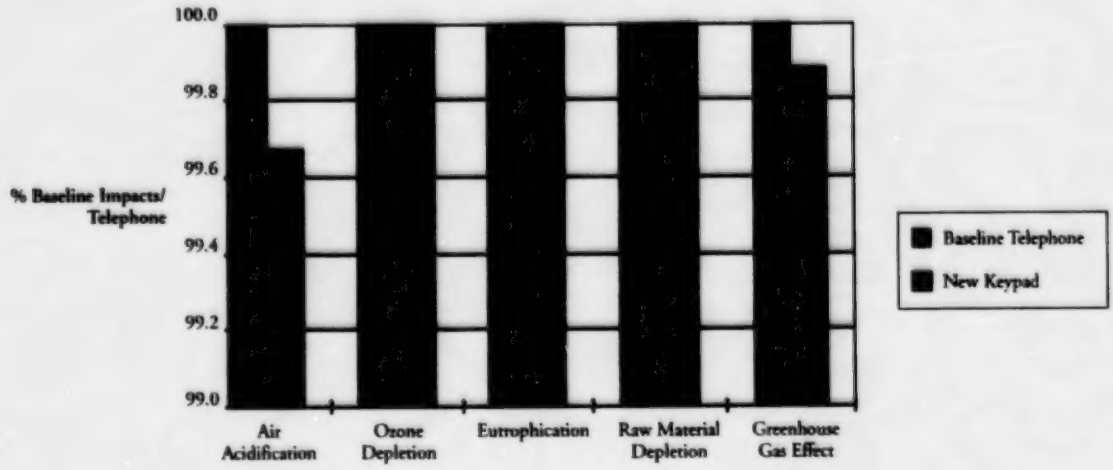


Figure 11 New Keypad Scenario — Total Life Cycle



5.2.3 *Thin-Walled Housing*

Figure 12 compares the effects of the thin-walled housing (cover assembly) scenario with the baseline case. Since the housing was not a major factor in any of the baseline impact indicators, changing it does not greatly affect the total life cycle impacts of the telephone.

5.2.4 *End-of-Life Options*

The following figures show the effects of changing the ratio of telephones sent to shredding at a facility in West Chicago, Illinois, rather than to a copper smelter in Rouyn-Noranda, Quebec. Overall, shredding is preferred to minimize raw material depletion and eutrophication, while copper smelting is preferred to minimize greenhouse gas effect and air acidification. Neither shredding nor copper smelting contributes to ozone depletion in the end-of-life phase.

Figure 12 Reduced Housing Scenario — Total Life Cycle

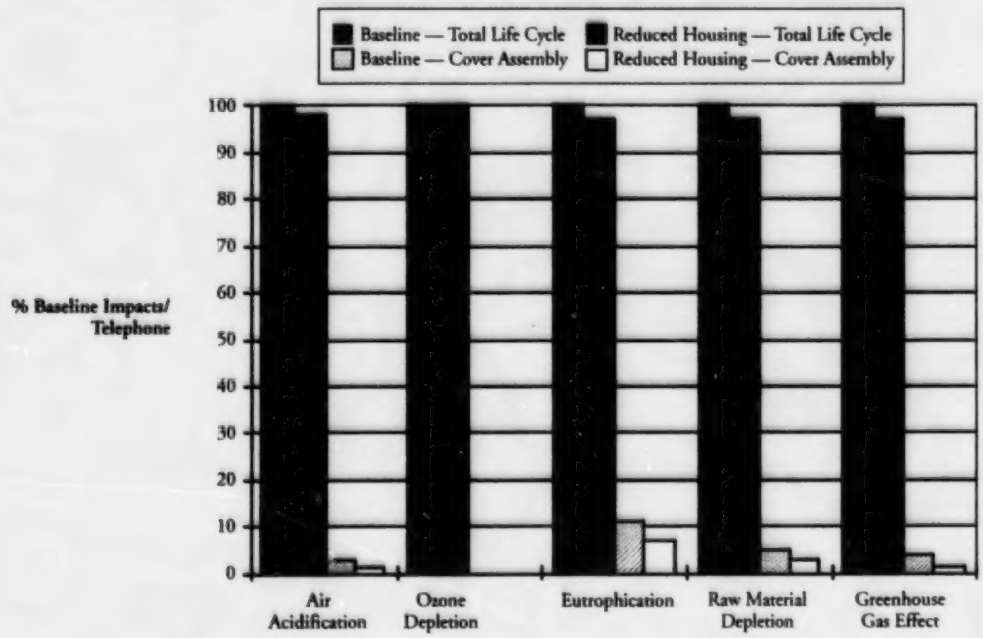
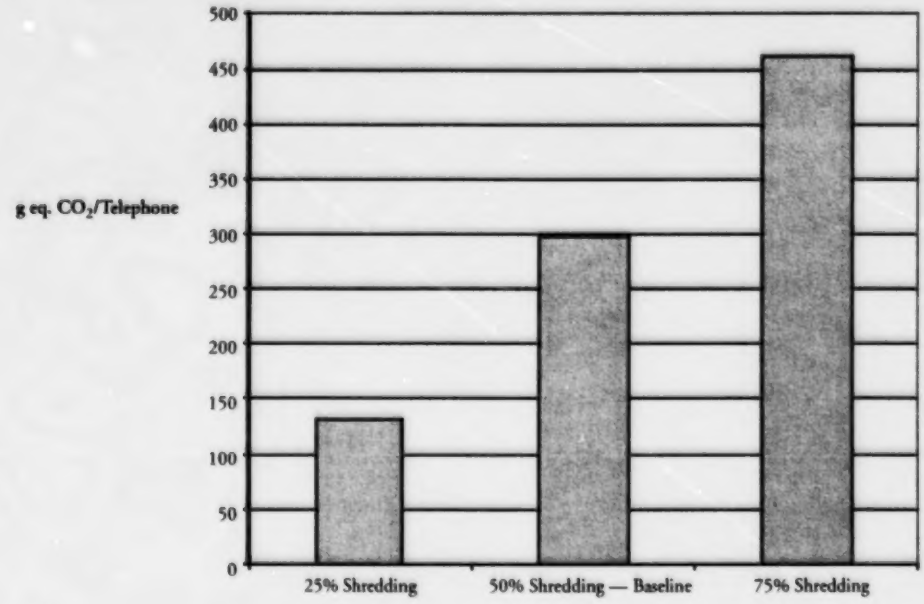


Figure 13 Greenhouse Gas Effect — End-of-Life Phase



As Figure 13 shows, increasing the proportion of telephones going to shredding increases the greenhouse gas effect because of the large amounts of electricity required for shredding. The end-of-life phase accounts for approximately 1 percent of the total greenhouse gas effect of the telephone over its life cycle.

Raw material depletion effects change very slightly from the 25 percent shredding scenario to the 75 percent shredding scenario, with the change representing approximately 2 percent of the total life cycle impact (Figure 14). This is not significant in the scope of a life cycle assessment.

Figure 14 Raw Material Depletion — End-of-Life Phase

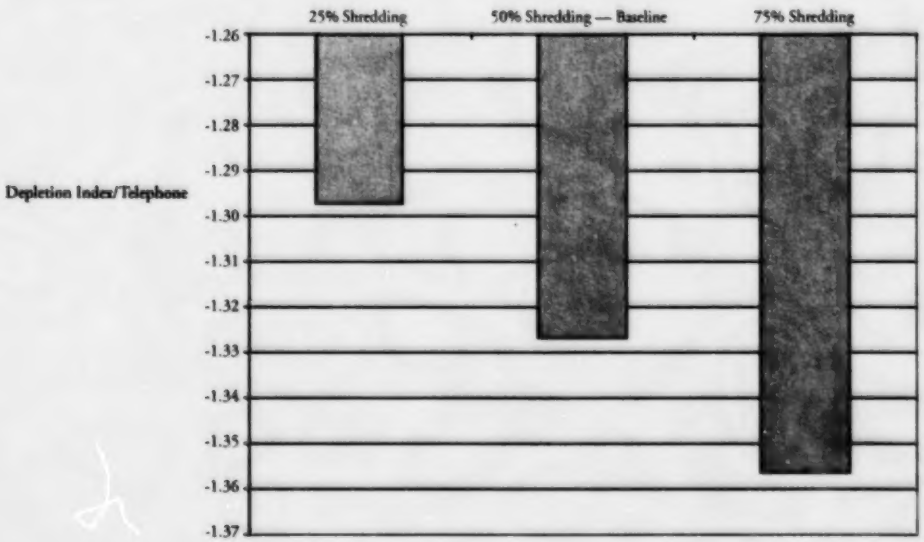
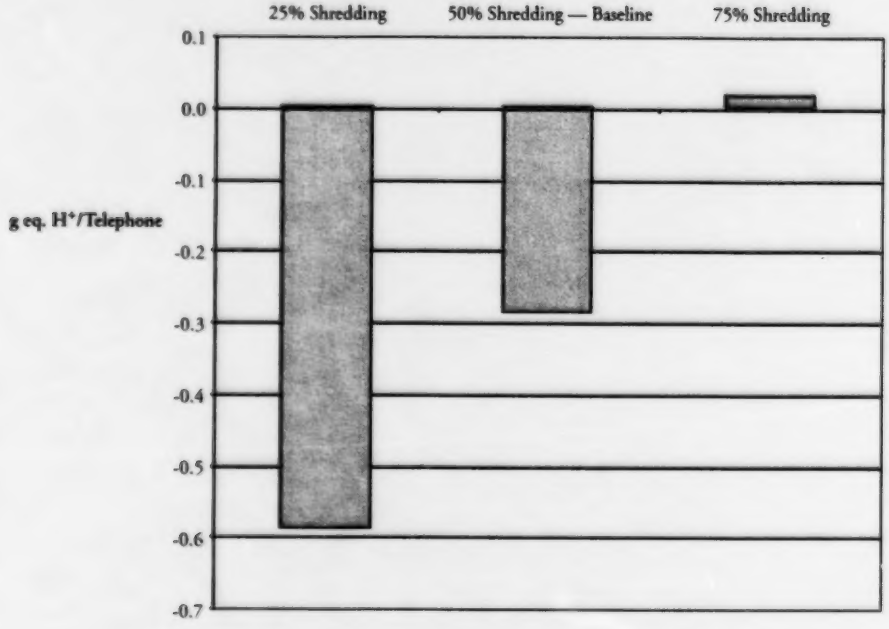
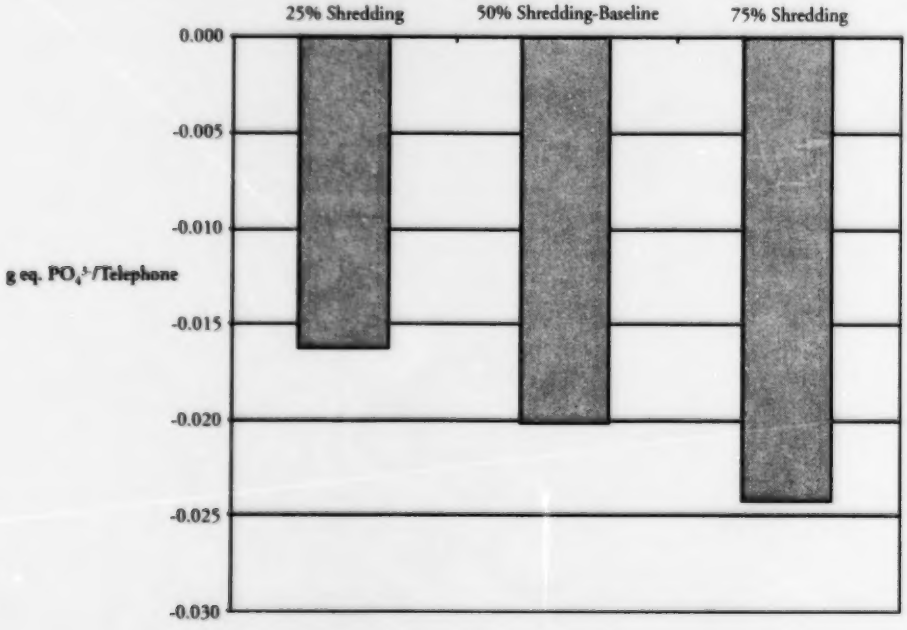


Figure 15 Air Acidification — End-of-Life Phase



The contribution to air acidification increases with increased shredding due to the high electricity consumption that occurs during shredding (Figure 15). Eutrophication effects change very slightly from the 25 percent shredding scenario to the 75 percent shredding scenario, with the change representing approximately 3.5 percent of the total life cycle impact. This is not significant in the scope of a life cycle assessment.

Figure 16 Eutrophication — End-of-Life Phase



6.0 Peer Review Process

The International Standard on Life Cycle Assessment (ISO 14040) recommends that life cycle assessment (LCA) studies that disclose their results to the public undergo an independent review process. For this study a third-party peer review was undertaken. The LCA study commissioners selected the panel chair, who in turn selected the remaining panel members. The panel for this review consisted of Scott Chubbs (Chair, Virterra Inc., Vancouver, B.C.), Bill Kiss (Ridgeway Research Corporation, Kanata, Ont.) and the team of Rob Macintosh and Marlo Raynolds (Pembina Institute for Appropriate Development, Drayton Valley, Alta.).

For this one-stage review, the panel drew on a number of resources to assist the evaluation, such as the experience of previous LCA efforts, guideline documents such as those published by the Society for Environmental Toxicology and Chemistry (SETAC), and the above-mentioned standard published by the International Organization for Standardization (ISO). The panel assessed the methods used to carry out the study, the appropriateness of the data used, the interpretation of the study results, and the degree to which the study report is transparent and consistent. However, the panel did not validate the study objectives or any subsequent application of the LCA results.

The panel found that although the project represented a good initial step in describing the life cycle of a business telephone, it had limitations in certain areas. These limitations centred primarily on the ability of the study to satisfy the second project objective identified in Section 3.1, namely, to develop guidelines for environmental design improvements for the next generation of Nortel Networks products.

This conclusion pinpoints a challenge faced by many LCA proponents and practitioners: how to effectively integrate the LCA data into decision-making processes within the company. A careful read of this case study indicates that design guidance is provided (see section 7), but the implementation of this guidance was a management issue that was affected by changing priorities in the company and timing issues associated with the completion of the LCA study. Consequently, the design for environment (DfE) scenarios were explored before the LCA was complete. Ideally, this situation would not arise, and the designers would have the benefit of the LCA results prior to exploring design improvements.

One way to avoid this type of problem would be to ensure that LCA data are better integrated into the design process through the use of software tools and design checklists that use indicators based on LCA data. Such an approach makes the information more readily available for decision making and is growing in popularity as more and more DfE software and tools come into the marketplace.

The peer review process was a useful exercise that provided direction on improving the transparency and communication of the study results.

7.0 Conclusions

7.1 Implications of Life Cycle Analysis Results

The use phase of electronic products is often a key contributor to environmental impacts, because of the electricity that is consumed. In this case, the telephone studied consumes small amounts of electricity (provided only by the telephone line connection) compared with more modern telephones that offer more functions and larger displays. Even though the telephone consumes relatively little electricity, this consumption occurs 24 hours a day, 7 days a week for over 10 years. About 80 percent of the power consumed by the telephone occurs when the telephone is not being used. This indicates the potential environmental gains from designing features that "power down" electronic products when they are not in use.

To reduce greenhouse gas emissions and air acidification, effort should be focused on reducing use phase electricity consumption and process electricity for electronics manufacturing, especially integrated circuits (ICs). Use phase energy efficiency can be improved by many techniques including powering down the product when it is not in use, using lower-power IC technology, new design architectures and power factor correction techniques. The business case for improving the energy efficiency of products is generally favourable, since energy costs (including energy purchases, capital costs associated with providing reliable power, and capital costs associated with air conditioning and ventilation to remove waste heat) are often a significant part of the total cost of product ownership for customers. This may not be entirely true for a simple telephone, but it is certainly the case for larger and more complex communication network products such as private branch exchanges or central office switches.

The opportunity for more meaningful reductions would increase if the design improvement were targeted at office telephone systems where a number of telephones are linked to a central switch. The benefits of making these improvements would need to be compared against those of other office energy efficiency improvement opportunities to ensure that the best return on investment was obtained with respect to reduced environmental impact. Any design improvement strategy would also need to take into account other design considerations to ensure that full functionality and performance were maintained.

IC manufacturing ranks first in terms of environmental impacts for the manufacturing stage. The fact that IC processing is complex and energy-intensive should not come as a surprise to anyone involved in the field. What is surprising is that its energy requirements often dwarf those of other components traditionally emphasized by LCA/DfE (such as plastic or metal housing, packaging, surface treatments). This finding may encourage changes in how the electronics industry defines and designs its products.

7.2 Potential Improvement Scenarios

When normalized per telephone, the impacts of the key system unit (KSU) proved to be three to five times larger than those of the telephone, pointing to larger potential savings from a DfE approach to this element of the overall system. In retrospect, perhaps this result should have been expected, given that most of the system intelligence and functionality is embodied in the KSU. Although it is difficult to generalize to other products and systems, this result may also help guide future decisions on where to focus LCA and DfE efforts for complex electronic systems.

The proposed new keypad technology and thin-walled housing did not significantly affect the total life cycle impact, for any of the impact categories or inventory flows. However, the case for these scenarios can still be made in terms of reduced assembly and manufacturing costs (and potential ease of disassembly), and the results illustrate the benefit of using LCA to complement other tools for an overall DfE approach.

The end-of-life scenario analysis looked at the effects of changing the ratio of telephones that are sent to shredding at a facility in West Chicago, Illinois, rather than a copper smelter in Rouyn-Noranda, Quebec. This analysis highlighted the trade-offs that are often inherent in evaluating end-of-life management options. The results showed that shredding is preferred to minimize raw material depletion and eutrophication. However, copper smelting is preferred to minimize the greenhouse gas effect and air acidification.

Nortel Networks has been actively pursuing energy efficiency opportunities at its IC manufacturing plant in Ottawa, Ontario, for several years. It appears that the semiconductor industry at large is also starting to pay more attention to this energy efficiency opportunity. For example, the world-renowned Rocky Mountain Institute in Colorado recently completed a study on energy efficiency for computer microchip fabrication plants (for more information, visit the Web site at: http://www.rmi.org).

7.3 Using LCA as a DfE Tool

This study confirmed that LCA is a systematic and useful tool for identifying the environmental impacts from a product throughout its life cycle. It is particularly useful for putting the many different environmental impacts from a product into perspective and identifying the dominant impacts. The results from an LCA can then be used to focus subsequent DfE efforts to ensure that limited resources are applied to the largest environmental burdens from the product (i.e., to getting the biggest bang for the buck from DfE).

To derive the most benefit from an LCA, it is necessary to complete the LCA and then use the results to guide the DfE process. As noted above, due to timing and resource constraints, this was not possible for this project. As a result, the DfE scenarios that were explored before the LCA was complete had little effect on the total life cycle impact for all impact categories and inventory flows.

To ensure relevance and management interest, the life cycle environmental analysis should be linked as much as possible to economic analysis. Further study would be required to more fully understand the cost-reduction opportunities that may arise from the study.

The time and resource (people and dollar) requirements for completing this LCA, using the traditional methodology described, were high. This is not unexpected when an organization is completing an initial LCA exercise, and costs could be expected to decline with experience. However, given that product development cycles in many industries are becoming shorter, it may not be realistic to include traditional LCA as part of a "live" product development process. Rather, LCA should be seen as an "off-line" DfE tool for identifying key strategies and guidelines for next generation product design.

The most challenging aspect of the LCA is access to good data. Although the data are often tracked, they are not collected centrally nor are they easily adapted for LCA purposes, (e.g., environmental emissions from a site are not usually allocated to specific products). In addition, data collection from primary sources can be particularly time-consuming.

The preceding discussion about the time and resource requirements involved in a traditional LCA indicates an ongoing need for simple and sophisticated DfE tools that can be easily integrated into existing design processes.

7.4 Summary Conclusions

From a general perspective, the project provided insights into the complexity of product systems such as the telephone, and the utility of tools such as LCA and DfE in improving the environmental performance of product systems.

Glossary of Terms

ABS
Abbreviation for acrylonitrile butadiene styrene. ABS is a type of plastic frequently used as the housing material for electronic equipment such as telephones, personal computers and fax machines.

Application Specific Integrated Circuit (ASIC)
A semiconductor chip that is produced for a specific application for a specific customer. ASICs are designed using a suite of computer-aided software programs. The design is simulated to predict its performance under worst case production tolerances. These simulations are used to guarantee performance of the production chips.

Air Acidification Potential
One of the indicators selected for this case study to translate inventory flows into environmental impacts. It measures the potential to create acid precipitation that can contaminate drinking water, damage vegetation and aquatic life, and erode buildings and monuments.

Central Office Switch (CO)
A facility to which the telephones in a public telephone network are connected. The CO is the location where the common carrier maintains the switching equipment and where telephone lines and trunks terminate. It is the front line in terms of the whole telephone system. Dial tone, telephone ringing, and connection to other telephones or outside trunks are done here.

Design for Environment (DfE)
The systematic consideration during design of issues associated with environmental safety and health over the entire product life cycle. DfE can be thought of as the migration of traditional pollution prevention concepts upstream into the development phase of products before production and use.

Ecolabelling
The labelling of products to provide information about the products' environmental attributes. A committee of the International Organization for Standardization (ISO) has classified ecolabel programs into three broad categories: third-party certification programs; manufacturer self-declarations; and environmental impact profiles.

Eutrophication Potential
One of the indicators selected for this case study to translate inventory flows into environmental impacts. It measures the potential to create an overabundance of nutrients in water that results in generally undesirable shifts in the number of species in ecosystems and a reduction in biodiversity. For example, eutrophication can increase algae growth, which can lead to lack of oxygen and therefore to the death of other species such as fish.

Global Warming Potential
One of the indicators selected for this case study to translate inventory flows into potential environmental impacts. This indicator measures the contribution to greenhouse gases from the product system, measured in terms of carbon dioxide equivalents. The Intergovernmental Panel on Climate Change (IPCC) has compiled a list of "provisional best estimates" for the global warming potential of various gases compared with carbon dioxide, based on the expert judgment of scientists worldwide. Because of its broad acceptance, this list has been used for this case study.

Inventory (elementary) Flow
This refers to material or energy entering the system being studied (which has been drawn from the environment without previous human transformation) and material or energy leaving the system being studied (which is discarded into the environment without subsequent human transformation) (definition from ISO 14041).

ISO 14000
The International Organization for Standardization has developed the ISO 14000 series of standards. These standards cover environmental management systems, environmental auditing, environmental labelling, environmental performance evaluation and life cycle assessment. These standards are voluntary standards for the establishment of a common worldwide approach to management systems that will help protect the earth's environment while spurring international trade.

Key System Unit (KSU)
The common equipment that operates key telephone systems. The KSU, also referred to as the key service unit, is normally served by loop start lines that can

appear on all telephone sets and operate without an operator console. A key telephone is a telephone that operates on a key system. Normally all of the lines that are on the system appear on the set.

Life Cycle Analysis (LCA)
A tool to assist with the quantification and evaluation of environmental burdens and impacts associated with product systems and activities, from the extraction of raw materials in the earth to end-of-life disposal. LCA is increasingly used by industries, governments and environmental groups to assist with decision making for environment-related strategies and materials selection. The initial phase of an LCA includes defining the goals and scope of a study, and the collection and calculation of life cycle inventory data.

Life Cycle Inventory (LCI)
One of the phases of a life cycle assessment. LCI data quantify the materials, energy and emissions associated with a functional system (e.g., the manufacture, distribution, use and disposal of 1 kg of hot rolled coil). This phase precedes the life cycle impact assessment and interpretation phases, which involve the classification, characterization and evaluation of these data in relation to environmental impacts.

Ozone Depletion Potential
One of the indicators selected for this case study to translate inventory flows into environmental impacts. It measures the potential to deplete the stratospheric ozone layer, which protects both humans and the non-human environment from the damaging effects of the sun's ultraviolet radiation.

Polycarbonate
A type of plastic. Polycarbonate is a stronger and more highly engineered material than ABS, is more expensive than ABS, and is used frequently as the plastic housing material for lightweight electronic equipment such as cell phones and laptop computers.

Private Branch eXchange (PBX)
"Exchange" refers to the equipment used at the telephone company when the operator used to connect all calls manually. The telephone company equipment was in the "central office" and was called central office exchange. The operator would answer the call, the customer would give the number wanted, and the operator would plug a cord into the appropriate jack. Service was only by a single telephone, since there was no multi-line telephone or telephone switch. Customers who wanted two lines had to have two separate telephones on their desks. To meet the increasing demand for equipment that would handle more than one line, the telephone company sold an "exchange" that could be used at a private company as a branch of the telephone company exchange. The system was called a private branch exchange. It allowed a company to have its own manual operator and to extend any incoming trunk to any station on the system. This allowed customers to be connected to all the trunks but have only one telephone on the desk.

Raw Material Depletion Index
One of the indicators selected for this case study to translate inventory flows into environmental impacts. This index measures the depletion of fossil fuel and mineral resources, taking into account both the absolute amount depleted by the product system and the scarcity of the raw material relative to existing reserves.

International Organization for Standardization (ISO) Standards

ISO 14000. 1996. *Environmental Management Systems — Specification with Guidance for Use.*

ISO 14040. 1998. *Life Cycle Assessment — Principles and Framework.*

ISO 14041. 1999. *Life Cycle Assessment — Inventory Analysis.*

ISO 14042. *Life Cycle Assessment — Impact Assessment.* Working draft.

ISO 14043. *Life Cycle Assessment — Interpretation.* Working draft.

Canadian Standards Association (CSA) Standards

CSA Standard PLUS 1107. 1994. *User's Guide to Life Cycle Assessment: Conceptual LCA in Practice.* ISSN 0383-2082.

CSA Standard Z760-94. 1994. *Life Cycle Assessment.* ISSN 0317-5669.

Internet Resources

For a comprehensive list of LCA publications, organizations (international, federal government, state government, companies) using LCA, ISO 14000, environmental agencies, national laboratories, academia, research institutes, NGOs, consultants, industry consortia, environmental and LCA software, and conferences related to LCA, refer to: **http://www.life-cycle.org**

Environment Canada, National Office of Pollution Prevention: **http://www3.ec.gc.ca/cppic/index_e.htm**

ECOCYCLE (an Environment Canada newsletter that shares information on policy and technical issues related to product environmental life cycle management): **http://www.ec.gc.ca/ecocycle**

European Environment Agency: **http://www.eea.eu.int**

Recycling Insights & Trade; Index to World Wide Web Links (provided by CPM, Inc.): **http://www.recycling-insights.com/index.html**

Sustainable Development (page maintained by the Center for Economic and Social Studies on the Environment, located at Université Libre de Bruxelles): **http://www.ulb.ac.be/ceese/meta/sustvl.html**

Website Associated with LCA and Ecodesign: **http://love.kaist.ac.kr/~kcr/links.htm**

International Organizations

European Environment Agency: **http://www.eea.eu.int**

The International Organization for Standardization (ISO): **http://www.iso.ch**

The International Environmetrics Society (TIES): **http://www.cciw.ca/environmetrics/intor.html**

United Nations Environment Programme (UNEP) — Work Group on Sustainable Product Development: **http://unep.frw.uva.nl**

The World Bank — Power Development, Efficiency and Household Fuels Division — The Environmental Manual for Power Development: **http://www.worldbank.org/html/fpd/em**

Electronic Journals

Ecosite (an electronic journal on LCA with editorial headlines and a virtual software shop): **http://www.ecosite.co.uk**

The Journal of Sustainable Product Design: **http://www.cfsd.org.uk/journal**

Product Stewardship Advisor (subscription required): **http://www.cutter.com/psa**

Hardcopy Journals

Ecomed Publishers (**http://www.ecomed.de**). *International Journal of LCA:* **http://www.ecomed.de/journals/lca/welcome1.htm**

MIT Press (**http://mitpress.mit.edu**). *Journal of Industrial Ecology:* **http://mitpress.mit.edu/journal-home.tcl?issn=10881980**

SETAC (Society for Environmental Toxicology and Chemistry). *SETAC LCA News:* **http://www.setac.org/news.html**

Books/Papers

Allenby, Braden R., and Thomas E. Graedel. 1995. *Industrial Ecology.* Prentice Hall College Div. ISBN 0131252380.

Ciambrone, David F. 1997. *Environmental Life Cycle Analysis.* Lewis Publishers, Inc. ISBN 1566702143.

Curran, Mary Ann (ed.). 1996. *Environmental Life-Cycle Assessment.* McGraw Hill. ISBN 007015063X.

Environment Canada. 1997. *Environmental Life Cycle Management — A Guide for Better Business Decisions.* ISBN 0-662-25636-0.

Fiksel, Joseph (ed.). 1995. *Design for Environment: Creating Eco-Efficient Products and Processes.* ISBN 0070209723.

Graedel, T.E., and B.R. Allenby. 1997. *Design for Environment.* Prentice-Hall Engineering/Science/Mathematics. ISBN 0135316820. (Discusses the effects of industrial actions on the environment. Focuses on environmental clean-up from our past while working toward future, environmentally sound industrial growth.)

IEEE International Symposium on Electronics and the Environment. 1995. *Proceedings of the 1995 IEEE International Symposium on Electronics and the Environment, ISEE: May 1–3, 1995, Orlando, Florida.* IEEE. ISBN 0780321375.

Keoleian, George A., and Dan Menerey. 1994. *Product Life Cycle Assessment to Reduce Health Risks and Environmental Impacts.* Noyes Publications. ISBN 0815513542.

Nordic Council of Ministers. 1995. *Nordic Guidelines on Life-Cycle Assessment.* ISBN 92-9120-692-X. pp. 45–49.

Ryding, Sven-Olof. 1995. *Environmental Management Handbook: The Holistic Approach from Problems to Strategies.* IOS Press. ISBN 9051990626.

Schaltegger, S., and Arthur Braunschweig (eds.). *Life Cycle Assessment (LCA) — Quo Vadis.* 1997. Birkhauser. ISBN 0817653414.

Society of Automotive Engineers. 1995. *Proceedings of the 1995 Total Life Cycle Conference (SAE Conference Proceedings, Vol. 293).* ISBN 1560916745.

Vigon, B.W. (ed.), and C.L. Harrison. 1994. *Life-Cycle Assessment: Inventory Guidelines and Principles.* Lewis Publishers, Inc. ISBN 1566700159.

Society for Environmental Toxicology and Chemistry (SETAC) Publications

Main Internet site: **http://www.setac.org./pubs.html**

Electronic Publications

A Conceptual Framework for Life-Cycle Impact Assessment: **http://www.setac.org./lca.html#S2**

Guidelines for Life-Cycle Assessment: A Code of Practice: **http://www.setac.org./lca.html#S3**

Life-Cycle Assessment Data Quality: A Conceptual Framework: **http://www.setac.org./lca.html#4**

A Technical Framework for Life-Cycle Assessment: **http://www.setac.org./lca.html#S1**

Hardcopy Publications

The following SETAC-Europe LCA Publications are available through the SETAC-Europe Office, Publications Department, Attn: Kim Courjaret, Av. E. Munier 83, Box 1, 1200 Brussels, Belgium, Tel.: 32 2 772 7281; Fax: 32 2 770 5386; e-mail: 100725.3525@compuserve.com

Allocation in LCA. 1994. Order no. 27.

Fourth LCA Symposium for Case Studies. 1996. Order no. 612.

Integrating Impact Assessment into LCA. 1994. Order no. 30.

Life Cycle Assessment: Inventory, Classification, Valuation, Data Bases. 1992. Order no. 22.

Third LCA Symposium for Case Studies. 1995. Order no. 611.

Towards a methodology for life cycle impact assessment. Order no. 41.

Appendix: Other Baseline Life Cycle Impact Indicator Results

I. Raw Material Depletion

Figures I.1 to I.8 illustrate the raw material depletion associated with various stages of the life cycle of an M7310 telephone. The data are based on baseline life cycle impact indicator results, the indicator here being raw material depletion. These results indicate which phase of the life cycle is the largest contributor to raw material depletion. The results also indicate which activities make the greatest contribution to raw material depletion within specific life cycle phases. Raw material depletion is quantified here as depletion index/telephone (except in Figure I.7, where it is depletion index/capacitor).

Figure I.1 shows a negative depletion index value for the end-of-life phase. This is because materials are recovered and thus are returned for future use during this phase. However, the negative end-of-life value is not as large as the manufacturing value, because not everything is recovered in the end-of-life phase, and what is recovered is not recovered with 100 percent efficiency.

Figure I.1 Raw Material Depletion for the Life Cycle Phases of an M7310 Telephone

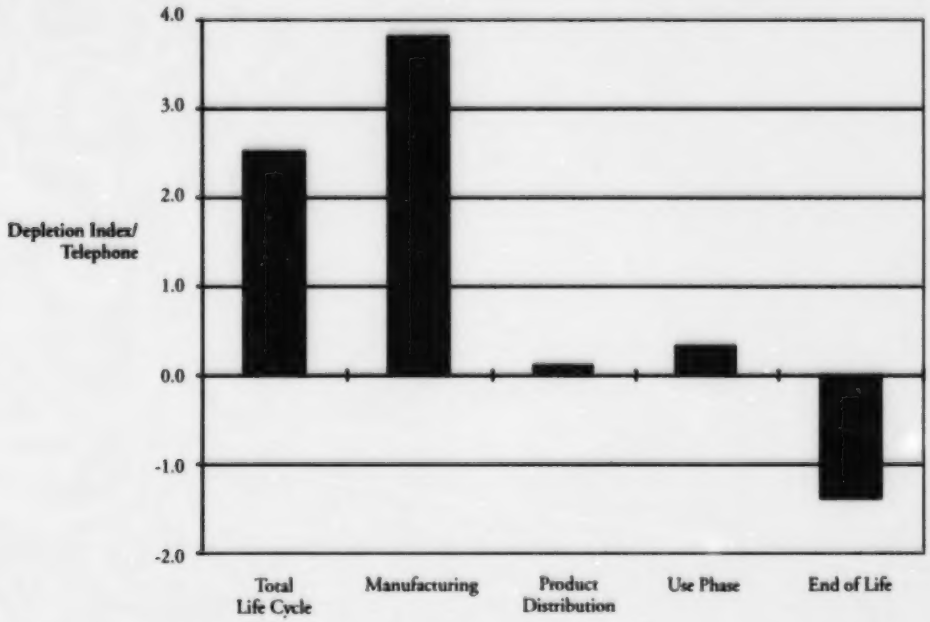


Figure I.2 Raw Material Depletion for the Various Components during Manufacture of an M7310 Telephone

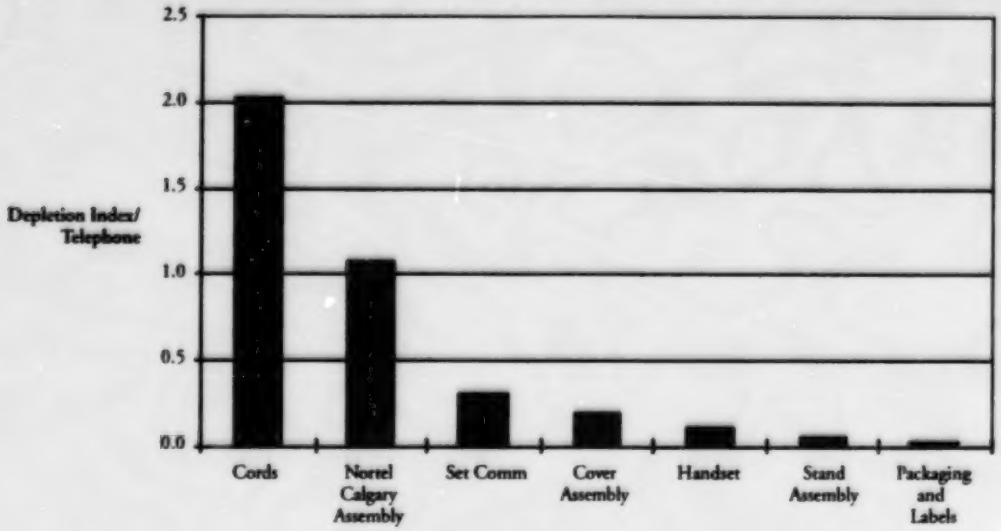


Figure I.2 above shows a breakdown of raw material depletion for the various components during manufacture.

As illustrated in Figure I.3, the copper used in the telephone cords causes this component to be the major contributor to raw material depletion.

Figure I.3 Raw Material Depletion for the Cords of an M7310 Telephone

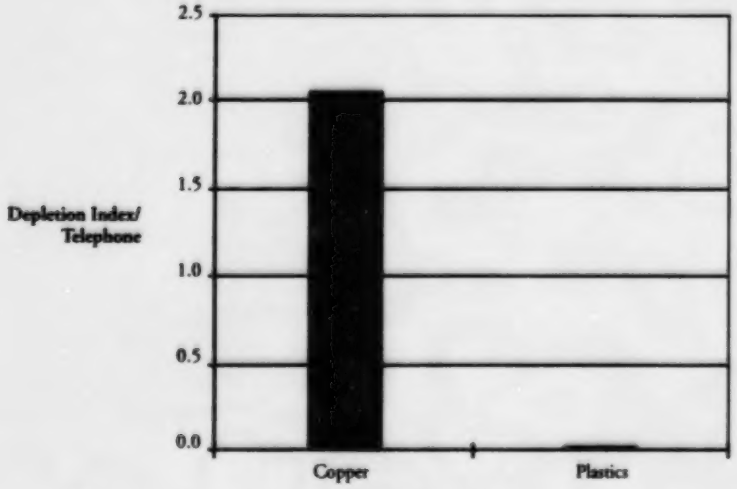
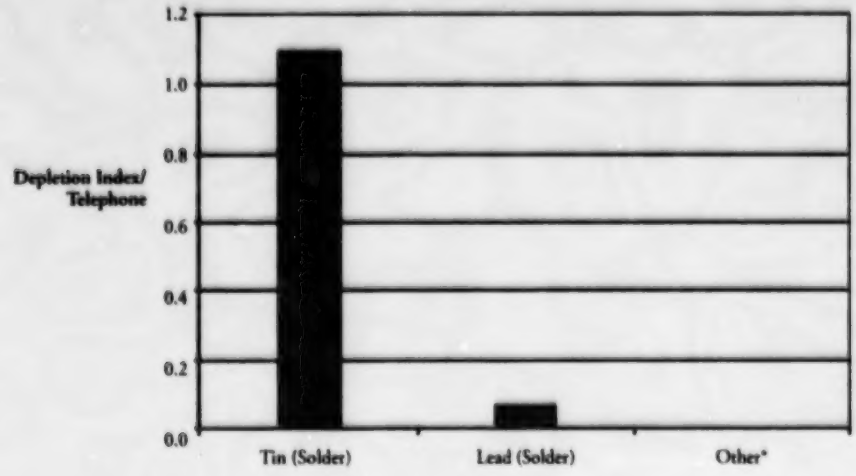


Figure I.4 Raw Material Depletion for Processes at Nortel Networks Calgary during M7310 Assembly

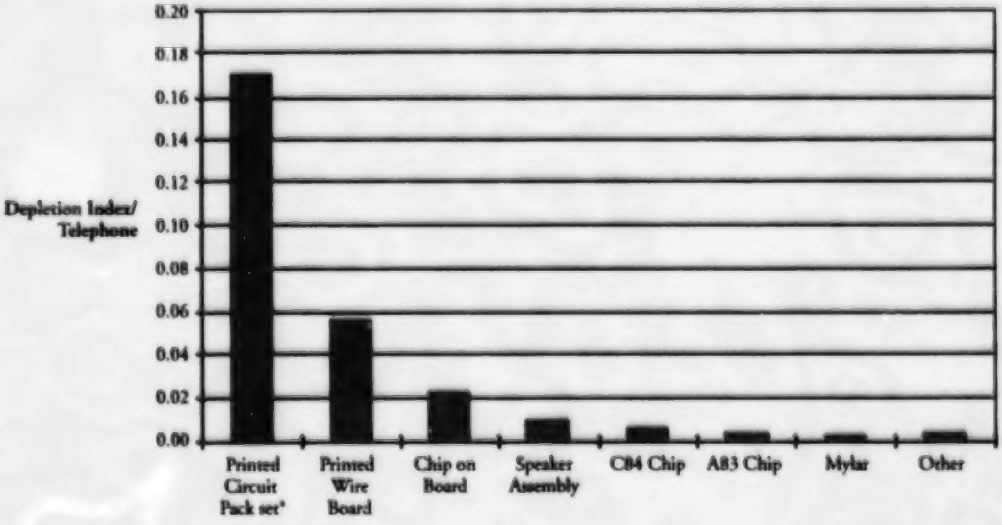


* Electricity, transport to assembly plant, etc.

Raw material depletion for the assembly process at Nortel Networks Calgary was due mainly to the solder, as shown in Figure I.4. However, the copper in the cords still contributes more to this raw material depletion index, since the amount of copper used in the cords is more significant than the tin and lead used in the solder for one M7310 telephone.

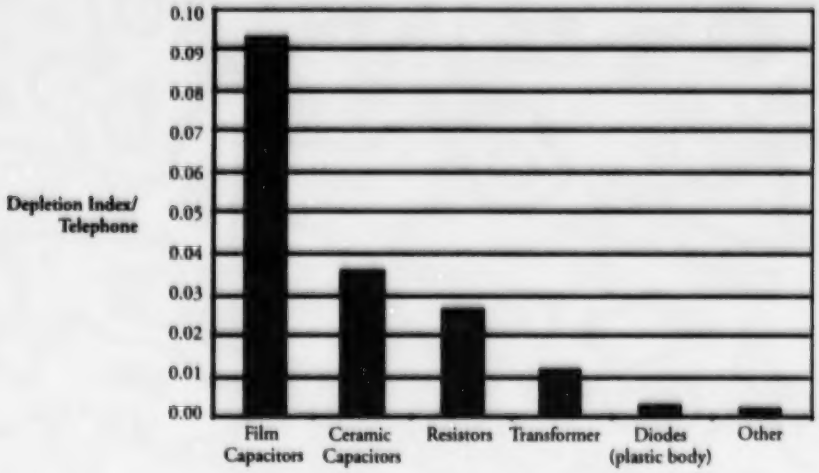
The electronics of the M7310 telephone contain metals, which cause the main electronic subassembly (Set Comm) to be the most significant contributor to raw material depletion. The contribution of the Set Comm is illustrated in Figure I.5 below.

Figure I.5 Raw Material Depletion for the Set Comm of an M7310 Telephone



* Other than C84, A83 printed wire board

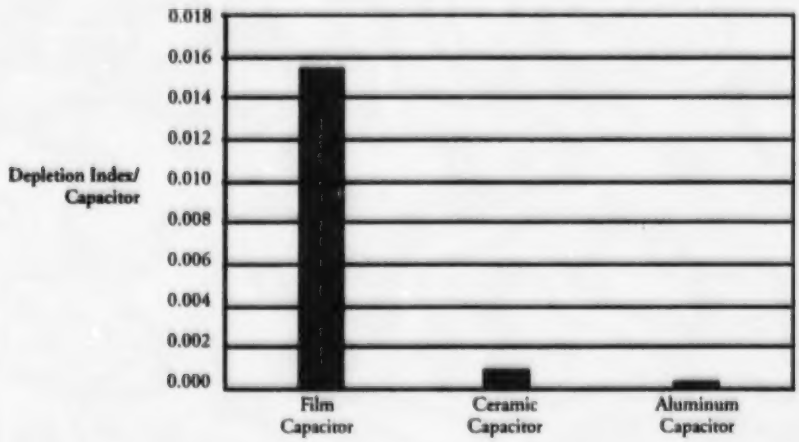
Figure I.6 Raw Material Depletion for the PCP Set (not including CB4, A83 or printed wire board) of an M7310 Telephone[1]



In the printed circuit pack set (PCP Set) category, film capacitors contribute the most to raw material depletion. The contribution from ceramic capacitors is due to their copper content, whereas that from resistors is due to tin content (Figure I.6).

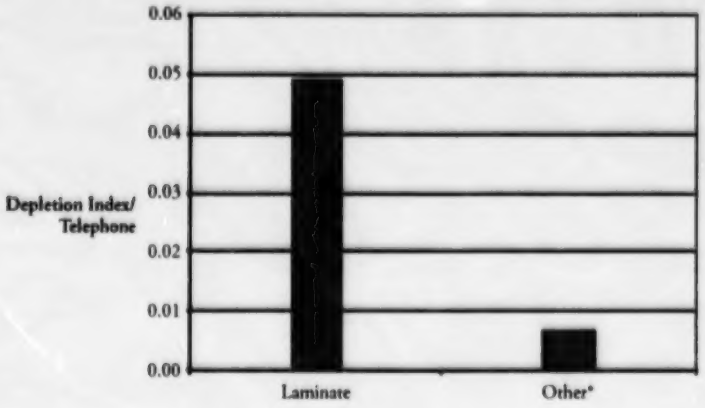
In Figure I.7 the relative contributions of each capacitor are reflected by the raw materials used for each component (i.e., tin in the film capacitor, copper in the ceramic capacitor and bauxite in the aluminum capacitor). It does not reflect a comparison of the capacitors' contribution to raw material depletion in one M7310 telephone.

Figure I.7 Raw Material Depletion for Individual Capacitors



[1] Data for all of these components come from Ecobalance's electronics database and not from primary data.

Figure I.8 Raw Material Depletion for the Set Comm Printed Wire Board of an M7310 Telephone



* Electricity, component transport, etc.

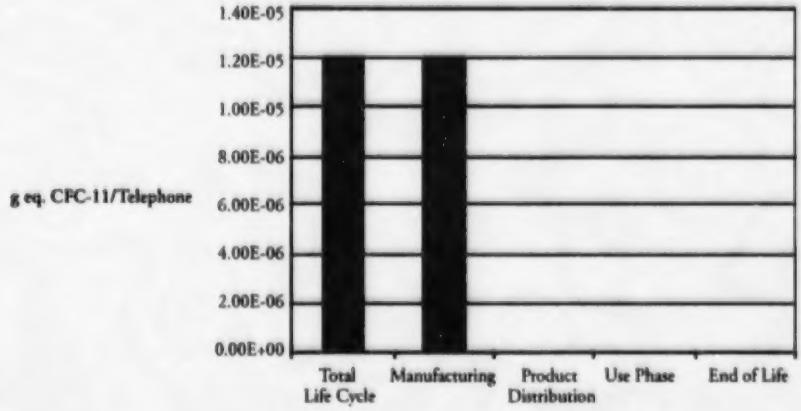
The raw material depletion of the printed wire board (Figure I.8) comes mainly from the copper contained in the laminate.

II. Ozone Depletion Potential

Figure II.1 illustrates the ozone depletion potential associated with various stages of the life cycle of an M7310 telephone. The data are based on baseline life cycle impact indicator results, the indicator here being ozone depletion potential. These results indicate which phase of the life cycle makes the greatest contribution to ozone depletion potential. The results also indicate which activities make the greatest contribution to ozone depletion potential within the manufacturing phase. Ozone depletion potential is quantified here as g equivalents (g eq.) of CFC-11/telephone.

All the ozone depletion effect comes from upstream component life cycle inventory data. The total emission results are very small (in the order of 10^{-5} g eq. CFC-11/telephone), and none of the primary data collected contribute to this ozone depletion effect.

Figure II.1 Ozone Depletion Potential for the Life Cycle Phases of an M7310 Telephone



III. Air Acidification

Figures III.1 to III.5 illustrate the air acidification impact associated with various stages of the life cycle of an M7310 telephone. The data are based on baseline life cycle impact indicator results, the indicator here being air acidification. These results indicate which phase of the life cycle makes the greatest contribution to air acidification. The results also indicate which activities make the greatest contribution to air acidification within the use phase. Air acidification is quantified here as g equivalents (g eq.) of H^+/telephone.

Most of the total life cycle effect for air acidification is derived from electricity consumption during the telephone's use phase in the United States. Air acidification from the use phase can be attributed mainly to emissions of sulphur oxides (SO_x) and nitrogen oxides (NO_x) (Figure III.1).

Figure III.1 Air Acidification for the Life Cycle Phases of an M7310 Telephone

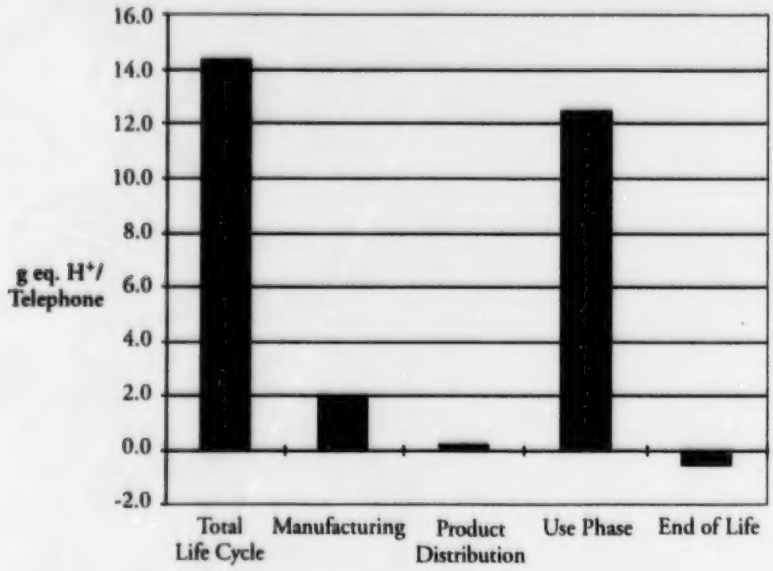
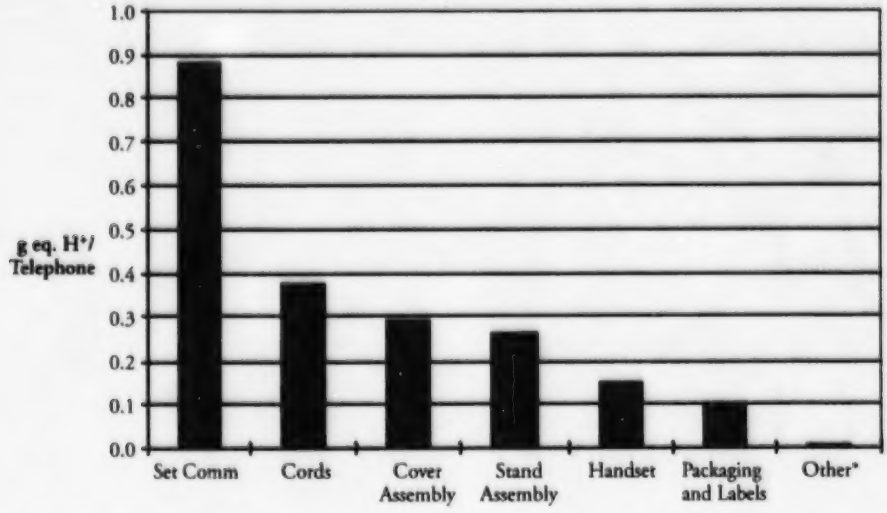


Figure III.2 Air Acidification in the Manufacturing Phase of an M7310 Telephone

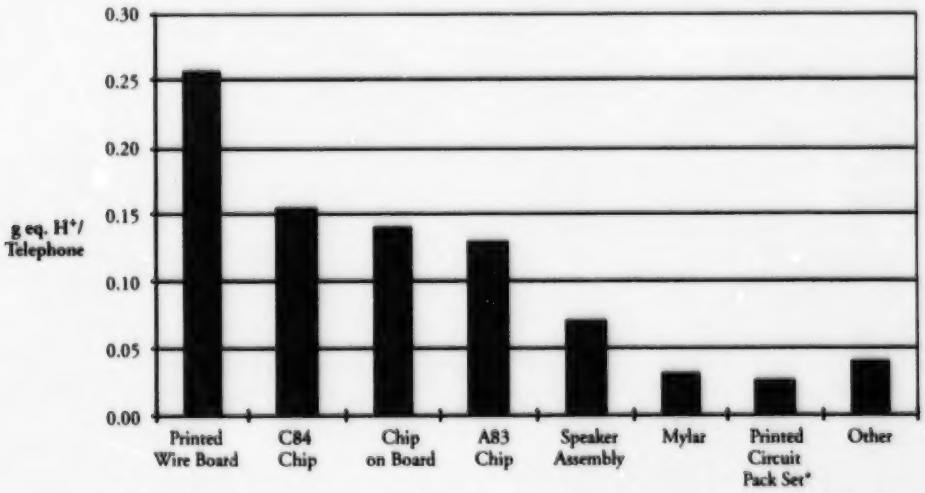


* Consumables, assembly plant electricity

As a comparison of Figure III.2 with Figure 6, air acidification for the manufacturing phase closely follows energy consumption. The remainder of the energy effects come mainly from the production of materials.

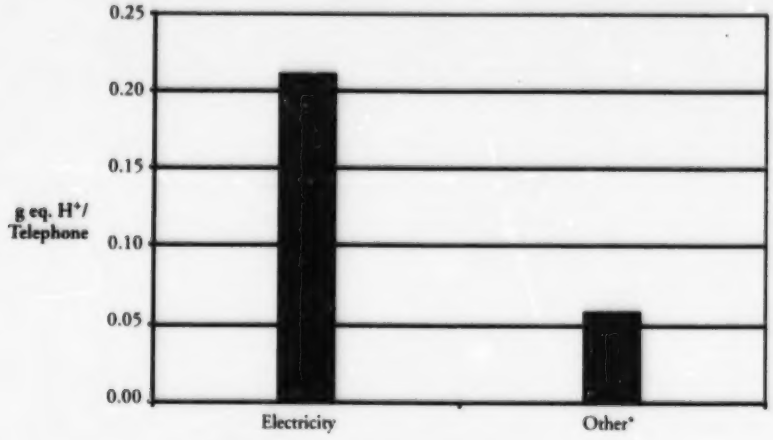
Figure III.3 shows that the printed wire board (PWB) is a larger contributor than the C84 chip to air acidification potential (as opposed to greenhouse gas effect). This is because significant amounts of SO_x and NO_x are emitted to air during production of the PWB laminate.

Figure III.3 Air Acidification for the Set Comm of an M7310 Telephone



* Other than C84, A83, printed wire board

Figure III.4 Air Acidification for the Set Comm Printed Wire Board of an M7310 Telephone

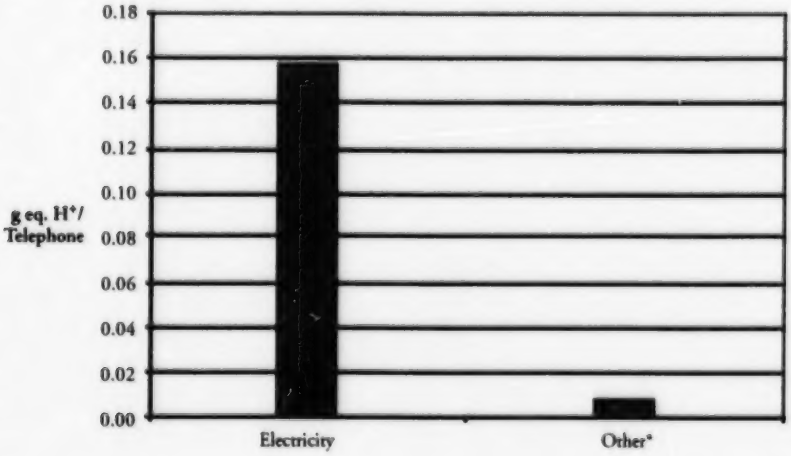


* Processing, materials, etc.

Figure III.4 illustrates the high contribution of electricity consumption to air acidification for the printed wire board. The "Other" category, which includes laminate production, also contributes significantly to the air acidification effect.

Figure III.5 shows electricity consumption during the process steps of the C84 chip to again be the main contributor to the air acidification effect. Air emissions from material production for the C84 chip are not significant in terms of air acidification.

Figure III.5 Air Acidification for the C84 Chip of an M7310 Telephone



* Processing, natural gas, consumables, etc.

IV. Eutrophication

Figures IV.1 to IV.4 illustrate the eutrophication effects associated with various stages of the life cycle of an M7310 telephone. The data are based on baseline life cycle impact indicator results, the indicator here being eutrophication. These results indicate which phase of the life cycle makes the greatest contribution to eutrophication. The results also indicate which activities are the largest contributors to eutrophication within the manufacturing phase. Eutrophication is quantified here as g equivalents of phosphate (PO_4^{3-})/telephone.

Most of the eutrophication effects are due to chemical oxygen demand (COD), ammonia compounds and nitrogenous matter compounds released in water effluents during the manufacturing stage (Figure IV.1).

Figure IV.1 Eutrophication Effects for the Life Cycle Phases of an M7310 Telephone

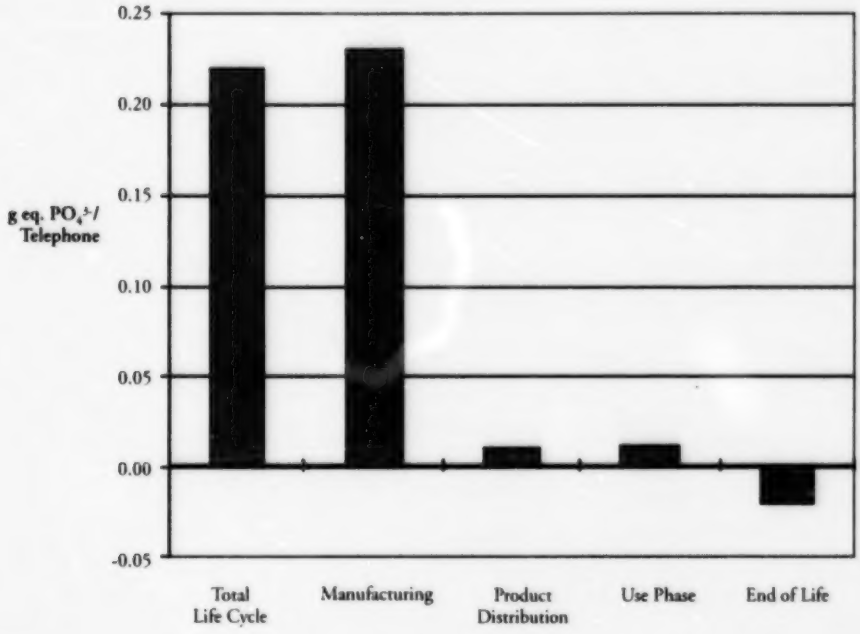
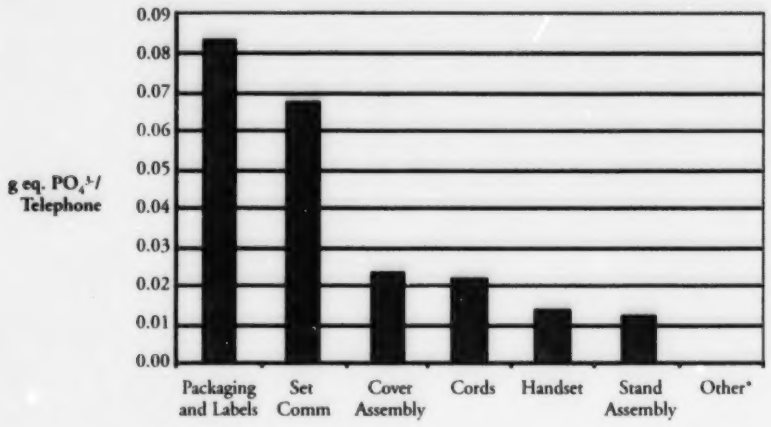


Figure IV.2 Eutrophication Effects for the Manufacturing Phase of an M7310 Telephone

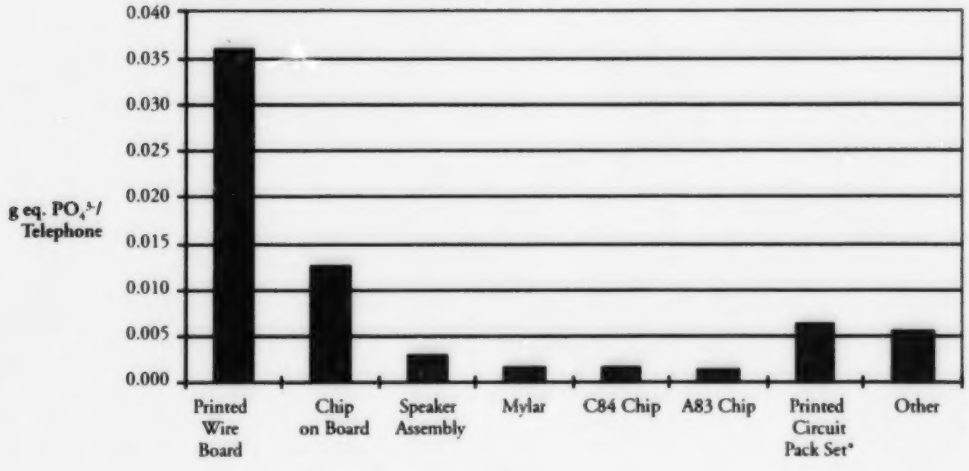


* Consumables, assembly plant electricity

Eutrophication is due primarily to the production of paper for packaging and labels (Figure IV.2). High COD water effluents are also released during ABS plastic production and are the main cause of eutrophication from the cover assembly and handset components. Production of polybutylene terephthalate plastic for the cords releases nitrogenous water effluents responsible for eutrophication.

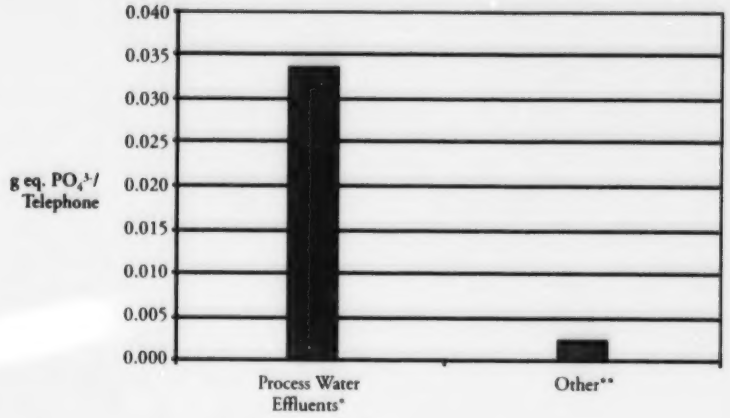
Process water effluents associated with the printed wire board are the primary contributor to eutrophication in the Set Comm (Figures IV.3 and IV.4). The Chip on Board (COB) was modelled from the printed wire board and, for this reason, it also contributes significantly to this effect.

Figure IV.3 Eutrophication Effects for the Set Comm of an M7310 Telephone



* Other than C84, A83, printed wire board

Figure IV.4 Eutrophication Effects for the Set Comm Printed Wire Board of an M7310 Telephone



* Ammonia, compounds, etc.

** Materials, electricity, etc.